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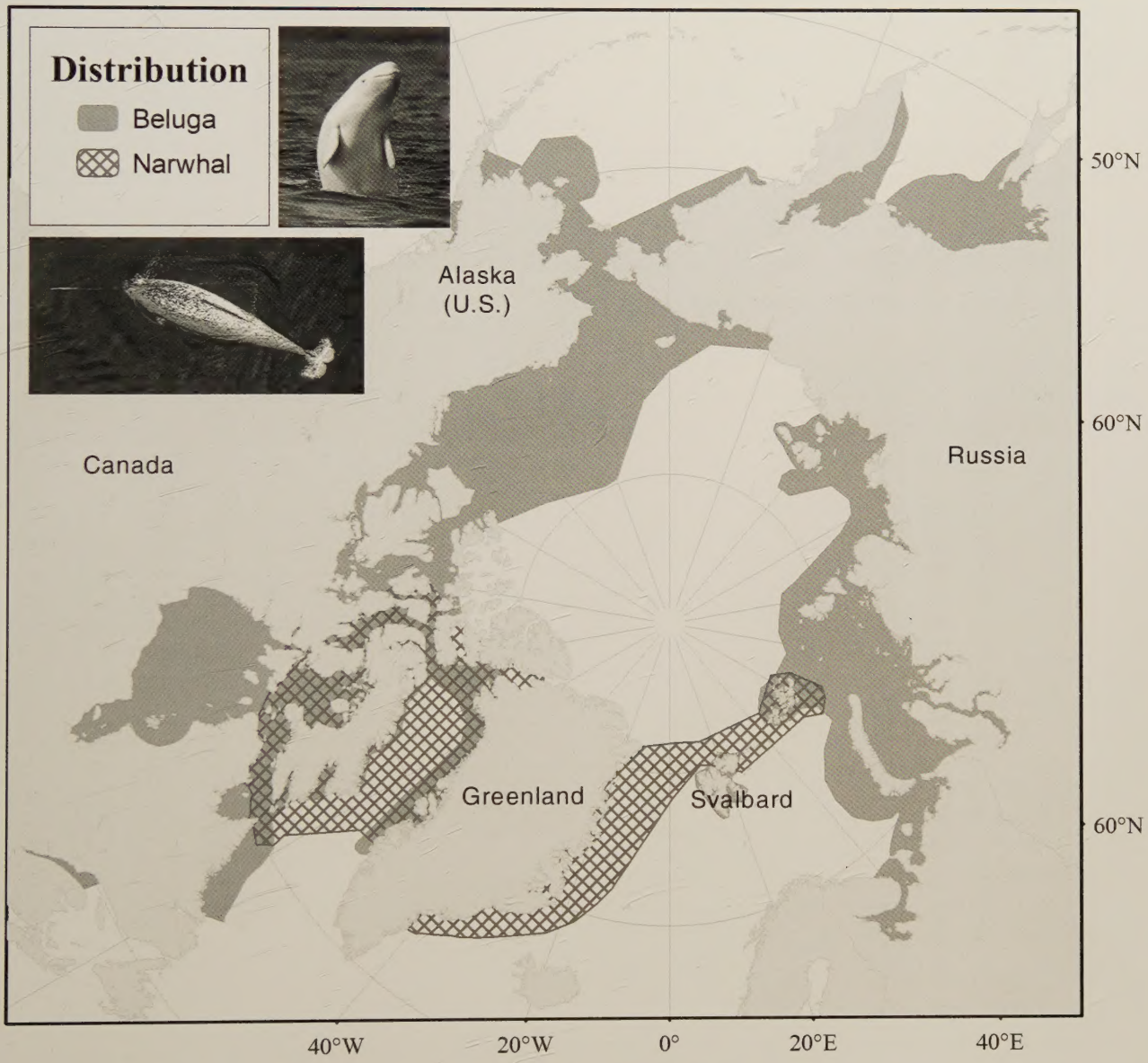

Conservation Status of Monodontid Stocks

Marine Fisheries REVIEW

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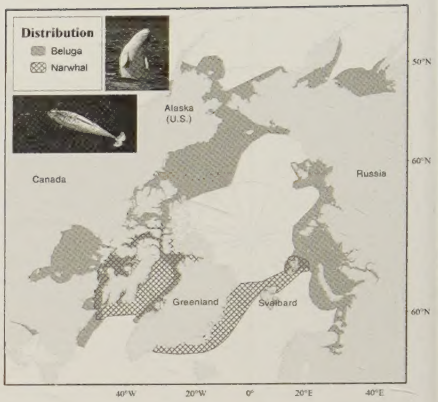

On the cover:
Circumpolar distribution of belugas and narwhals including summer and winter areas and migratory paths. Top photo: Spyhopping beluga, photographed from shore on Cape Beluzhiy, Solovetskiy Island, White Sea in 2010 (Copyright Bettina van Elk (Netherlands)). Bottom photo: Male narwhal resting at the surface in Dove Bay, Northeast Greenland National Park in 2018 (Copyright Carsten Egevang).

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Global Review of the Conservation Status of Monodontid Stocks

Preface

Two modern species of toothed whales, the narwhal, *Monodon monoceros,* and the beluga or white whale, *Delphinapterus leucas*, comprise the family Monodontidae. Both are endemic to the Arctic and, in the case of belugas, also certain portions of the sub-Arctic. While the narwhal's range is centered in high-latitude waters connected to the North Atlantic Ocean (eastern Canada, Greenland, Svalbard, and Franz Josef Land), the beluga's distribution is nearly circumpolar, with substantial populations not only in the High Arctic but also in the Sea of Okhotsk, the southern Bering Sea, Hudson Bay, the northern Gulf of Alaska, and the St. Lawrence River estuary. Range states of monodontids are the Russian Federation, the United States of America, Canada, Denmark (Greenland), and Norway.

In addition to government agencies within those states, several international and regional bodies are involved in the assessment and conservation of beluga and narwhal populations. The oldest and most inclusive of these (in terms of number of state members) is the International Whaling Commission (IWC). Among its 89 member countries are four of the five monodontid range states (Canada being the sole non-member).

The Scientific Committee of the IWC has on two occasions reviewed the world's stocks of belugas and narwhals (both species in 1992, IWC, 1993; only belugas in 1999, IWC, 2000). These reviews identified 29 stocks of belugas and 3 regional stocks of narwhals. Beluga stocks were considered in detail, and available information on range, abundance, trends in abundance, hunting removals, threats, and legal status were reviewed and summarized. The reviews identified four stocks of highest concern due to small population size, depletion from historical levels, and currently declining trend, and it made recommendations regarding future research.

In the North and Arctic Atlantic, two regional management bodies operate. The Canada-Greenland Joint Commission on the Conservation and Management of Narwhal and Beluga (JCNB) was established in 1991 to conserve and manage the shared stocks of narwhals and belugas (i.e., those stocks that migrate between Canadian and Greenlandic waters and spend at least part of each year within the EEZ of each country). The JCNB makes recommendations on the conservation and management of these shared stocks to the appropriate authorities of both countries.

The North Atlantic Marine Mammal Commission (NAMMCO) was established in 1992 by the Faroe Islands, Greenland, Iceland, and Norway to cooperate in the management and conservation of all marine mammals in the area. NAAMCO regularly reviews the status of the stocks of narwhals and belugas within its remit.

The NAMMCO Scientific Committee's Working Group on the Population Status of Beluga and Narwhal in the North Atlantic (NBWG) met for the first time in 1999 and carried out a detailed review of all stocks of both species in Atlantic and adjacent waters (NAMMCO[1]). In 2000, the NBWG carried out an assessment of belugas in West Greenland and concluded that the stock there was substantially depleted and that harvest levels were several times the sustainable yield, likely leading to extirpation of the stock within

doi: https://doi.org/10.7755/MFR.81.3–4.p

[1]NAMMCO. 2000. Report of the 7th Meeting of the NAMMCO Scientific Committee. *In* NAMMCO (Editor), Annual report 1999, p. 125–214. N. Atl. Mar. Mammal Comm., Tromsø, Norway (avail. at http://nammco.wpengine.com/wp-content/uploads/2016/08/Annual-Report-1999.pdf).

20 years. The NAMMCO Scientific Committee endorsed this conclusion and recommended various conservation measures, including the immediate reduction of harvests to prevent further decline of the stock, as well as prioritized research topics (NAMMCO, p. 136–145 and Annex 3)[2]. Close cooperation between the Scientific Committees of NAMMCO and the JCNB was recommended (NAMMCO, p. 75)[3] and a Joint Working Group (JWG) was established, which met for the first time in 2001 and has reviewed and assessed the status of shared stocks regularly since then (2004, 2005, 2009, 2012, 2014, 2015, 2017[4]). "National" stocks are assessed either within the framework of NAMMCO or by a national management body separately.

During the decade following 1999, as substantial new information on the delineation and status of beluga and narwhal stocks became available, the need to update the previous reviews became increasingly evident. At its annual meeting in 2010, the IWC Scientific Committee's Standing Sub-committee on Small Cetaceans noted that a "joint special meeting or workshop on monodontids" involving the IWC, NAMMCO, and the JCNB "should be considered in the near future" (IWC, 2011:287). At its next meeting, the sub-committee was advised that an intersessional correspondence group had "moved ahead … on planning a proposed global review of monodontids (involving, at a minimum, IWC, NAMMCO, and the JCNB)" (IWC, 2012:279).

In 2012 the sub-committee noted that NAMMCO had indicated an interest in organizing and convening the review jointly with the IWC Scientific Committee. The sub-committee formally recommended this approach (IWC, 2013a:296), which was endorsed by the full Committee, and a steering committee (consisting of Arne Bjørge from Norway, Randall Reeves and Robert Suydam from the United States, Steve Ferguson from Canada, and representatives of the IWC (Greg Donovan) and NAMMCO (Christina Lockyer, Mario Acquarone, and later Jill Prewitt)) secretariats were duly appointed to pursue planning and implementation (IWC, 2013b:58). Although the Global Review of Monodontids workshop continued to be discussed at annual IWC Scientific Committee meetings (IWC, 2014:362), the Sub-committee on Small Cetaceans was advised in 2014 that NAMMCO had decided to convene and undertake the global review separately from the IWC (IWC, 2015:307). We emphasize, however, that scientists from the range states, including those who regularly participate in either the IWC Scientific Committee or the NAMMCO Scientific Committee and NBWG, or both, continued to collaborate closely in planning and conducting the review workshop.

The steering committee for the workshop was expanded to include the chair of the NBWG and NAMMCO co-chair of the JWG (Rod Hobbs), a representative of the Arctic Council's Conservation of Arctic Flora and Fauna secretariat (Tom Barry), and scientists from Russia (Olga Shpak) and Greenland (Rikke Guldborg Hansen, JCNB co-chair of the JWG). The committee developed the terms of reference and agenda for the workshop and identified subject experts for each potential monodontid stock as well as other experts who would be invited to participate. Subject experts provided reports on the status of the stocks and potential stocks prior to the workshop. These reports were reviewed during the workshop and in some cases revised in response to comments received from participants. A report of the workshop and the compiled stock reports were then posted on the NAMMCO website (NAMMCO[5]).

This issue of *Marine Fisheries Review* includes a revised and updated version of the workshop report (Hobbs et al., 2019) and several related papers that were developed by workshop participants. Three of these papers concern stocks of belugas in the Russian Far East (Shpak et al., 2019) and western Alaska (Lowry et al., 2019; Citta et al., 2019). Most of the recognized beluga stocks are differentiated by mitochondrial DNA (mtDNA) data, and Skovrind et al. (2019) provide a circumpolar review of beluga mtDNA variation. NAMMCO has developed a metapopulation model for the narwhal stocks that winter in Baffin Bay, and Watt et al. (2019) explain how this model is used to allocate catches by the communities that hunt the narwhals from this metapopulation to the individual stocks. Statistics on removals of narwhals by hunting in Greenland from 1862 to 2017 (Garde et al., 2019) were used with other data and the metapopulation model in a Bayesian analysis to generate management advice for the Baffin Bay narwhal stocks (Witting et al., 2019).

Finally, this issue is dedicated to the memory of Lloyd Lowry, who died in late November 2018, soon after completing editing of the report on western Alaska beluga stocks (Lowry et al., 2019). Lloyd was a long-time beluga researcher and advocate for marine mammal conservation in Alaska and worldwide. He was instrumental in establishing the Alaska Beluga Whale Committee and remained an active member of that committee for over 30 years. See Gulland et al. (2019) for further details of Lloyd's life.

Roderick Hobbs, Jill Prewitt, Randall Reeves, and Genieviéve Desportes

[2]NAMMCO. 2001. Report of the 8th Meeting of the NAMMCO Scientific Committee. *In* NAMMCO (Editor), Annual report 2000, p. 123–296. N. Atl. Mar. Mammal Comm., Tromsø, Norway (avail. at http://nammco.wpengine.com/wp-content/uploads/2016/08/Annual-Report-2000.pdf).

[3]NAMMCO. 2001. Report of the NAMMCO Management Committee. *In* NAMMCO (Editor), Annual report 2000, p. 73–122. N. Atl. Mar. Mammal Comm., Tromsø, Norway (avail. at http://nammco.wpengine.com/wp-content/uploads/2016/08/Annual-Report-2000.pdf).

[4]Reports of the Joint Working Group (avail. at https://nammco.no/topics/sc-wg-reports/).

[5]NAMMCO. 2018. Report of the NAMMCO Global Review of Monodontids. 13–16 March 2017, Hillerød, Denmark (avail. at https://nammco.no/wp-content/uploads/2018/05/report-global-review-of-monodontids-nammco-2018_after-erratum-060518_with-appendices_2.pdf).

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Global Review of the Conservation Status of Monodontid Stocks
Glossary of Terms, Acronyms, and Abbreviations

JILL PREWITT, RANDALL REEVES, and RODERICK HOBBS

Aggregations

Groups of individuals of a species in summering, wintering, or migrating areas. The modifier "recurring" or "seasonal" is used when aggregations are known to repeat annually or otherwise regularly.

AI

Admiralty Inlet; body of water in Nunavut, Canada; in this issue, a narwhal stock that aggregates in Admiralty Inlet in summer (August).

Availability Bias

When animals are missed by a survey due to being submerged or otherwise unavailable for detection; availability bias can be estimated with data on dive times, surfacing intervals, and location, and a correction factor can be applied to the survey results to remove the bias.

CAFF

Conservation of Arctic Flora and Fauna; a working group of the Arctic Council.

COSEWIC [Canada]

Committee on the Status of Endangered Wildlife in Canada; an independent advisory panel to the Minister of Environment and Climate Change Canada, established under the Species At Risk Act of 2002. The committee meets twice a year to assess the risk of extinction of wildlife species; status categories include Extinct, Extirpated, Endangered, Threatened, Special Concern, Data Deficient, Not at Risk (https://www.canada.ca/en/environment-climate-change/services/committee-status-endangered-wildlife.html).

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Critical Habitat (ESA [USA])

ESA designation of specific areas either 1) within the geographical area occupied by the species at the time of ESA listing, if they contain physical or biological features essential to conservation, and the features may require special management considerations or protection or 2) outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation.[1]

Critical Habitat (SARA [Canada])

SARA designation of habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in a recovery strategy or in an action plan for the species.[2]

Critically Endangered (IUCN)

Red List designation of a species, subspecies, or "subpopulation" (as defined in the Guidelines) that is facing an extremely high risk of extinction in the wild.[3]

CS

Cumberland Sound; body of water in Nunavut, Canada; in this issue, a beluga stock residing therein.

Data Deficient (Norwegian Red List)

Red List designation of a species or population that is at risk of extinction, but for which there is considerable uncertainty about the degree of risk.[4]

Data Deficient (IUCN)

Designation of a species for which the data available are insufficient for placing it in one of the risk categories (e.g., Endangered, Vulnerable).[3]

Depleted (MMPA [USA])

Any species or "population stock" (a term used in the MMPA) that is below its optimum sustainable population size or is listed as an endangered or threatened species under the ESA.[5]

Depleted (general definition)

A population that is below its maximum sustainable yield (MSY) level.

DFO [Canada]

Fisheries and Oceans Canada (formerly Department of Fisheries and Oceans).

Distinct Population Segment (DPS) (ESA [USA])

A vertebrate population or group of populations that is discrete from other populations of the species and significant in relation to the entire species. The ESA provides for listing species, subspecies, or distinct population segments of vertebrate species.[6]

[1]Critical Habitat What is it? U.S. Fish and Wildlife Service, Dep. Interior. (https://www.fws.gov/endangered/esa-library/pdf/critical_habitat.pdf).

[2]A guide to the Species At Risk Act (SARA): Information for federal land managers (https://www.registrelep-sararegistry.gc.ca/6AC53F6B-550E-473D-9BDB-1CCBF661F521/fedland-eng.pdf).

[3]IUCN Red List Categories and Criteria (https://www.iucnredlist.org/resources/categories-and-criteria).

[4]How the Red List is compiled (https://www.biodiversity.no/Pages/135393/How_the_Red_List_is).

[5]Lowry, L., D. W. Laist, E. Taylor. 2007. Endangered, Threatened, and Depleted Marine Mammals in U. S. Waters: A review of species classification systems and listed species (avail. at https://www.mmc.gov/wp-content/uploads/etdmarinemammals.pdf).

[6]Endangered Species Act Section 3. U.S. Fish and Wildlife Service, Dep. Interior (avail. at https://www.fws.gov/endangered/laws-policies/section-3.html).

EBI
Eastern Baffin Island; in this issue, a narwhal stock that summers along the east coast of Baffin Island.

EBS
Eastern Beaufort Sea; in this issue, a beluga stock that summers in the eastern Beaufort Sea.

EHB
Eastern Hudson Bay; in this issue, a beluga stock that summers in eastern Hudson Bay.

Endangered (COSEWIC) [Canada]
COSEWIC designation of a wildlife species (encompassing subspecies and "designatable units"—a term specific to SARA) that is facing imminent extirpation or extinction.[7]

Endangered (ESA [USA])
ESA designation of a species, subspecies, or distinct population segment that is in danger of extinction throughout all or a significant portion of its range.[6]

Endangered (IUCN)
Red List designation of a species, subspecies, or "subpopulation" (as defined in the Guidelines) that is facing a high risk of extinction in the near future.[3]

ES
Eclipse Sound; body of water in Nunavut, Canada; in this issue, a narwhal stock that aggregates in Eclipse Sound in summer.

ESA - Endangered Species Act [USA]
U.S. law enacted in 1973 to conserve and protect endangered and threatened species and their habitat; status listings include Endangered, Threatened, Candidate (species being considered for listing). Habitat essential for the species is legally designated as "Critical Habitat."[6]

GROM
Global Review of Monodontids.

IB
Inglefield Bredning; a body of water in West Greenland; in this issue, a narwhal stock that aggregates in Inglefield Bredning in summer.

IWC
International Whaling Commission; international body established under the 1946 International Convention for the Regulation of Whaling to "provide for the proper conservation of whale stocks and thus make possible the orderly development of the whaling industry". In recent years it has become increasingly involved in assessment of small cetaceans and in cetacean conservation issues not directly related to whaling.[8]

IUCN
International Union for Conservation of Nature; international organization in the field of conservation of natural resources; holds observer and consultative status in the United Nations; plays a role in the implementation of several international conventions on nature conservation and biodiversity; manages the Red List of Threatened Species.[9]

IUCN Red List
A system of assessing the global conservation status of species, subspecies, and "subpopulations" (as defined in the Guidelines); categories include Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern.[10]

JB
James Bay; body of water in Southern Hudson Bay, Canada; in this issue, a beluga stock with its distribution centered in James Bay.

JCNB
Canada/Greenland Joint Commission on the Conservation and Management of Narwhal and Beluga.[11]

LRC [Canada]
Loss Rate Correction; a correction factor applied to landings to account for struck-but-lost animals (shot, harpooned, etc., but not secured and counted in catch statistics) in estimating removals from the population.

MB
Melville Bay; a body of water in West Greenland; in this issue, a narwhal stock that aggregates in Melville Bay in summer.

Monodontids
Cetaceans in the family Monodontidae, comprising two extant species—the beluga and the narwhal.

MMPA - Marine Mammal Protection Act [USA]
U.S. law enacted in 1972 to protect all marine mammals; among other things, it prohibits the "taking" (see "Takes (MMPA [USA])") of marine mammals, and establishes a moratorium on the importation, exportation, and sale of any marine mammal, or any marine mammal part or product.[12]

MSYL
Maximum Sustainable Yield Level; "the greatest harvest that can be taken from a self-regenerating stock of animals year after year while still maintaining a constant average size of the stock" (Holt and Talbot, 1978:Appendix 3).

mtDNA
mitochondrial genetics (DNA = deoxyribonucleic acid).

[7]COSEWIC definitions and abbreviations: Approved by Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in November 2017 (https://www.canada.ca/en/environment-climate-change/services/committee-status-endangered-wildlife/definitions-abbreviations.html).

[8]The International Whaling Commission (IWC) (https://iwc.int/home).

[9]International Union for Conservation of Nature (IUCN) (https://www.iucn.org/).

[10]IUCN. Red List of Threatened Species (https://www.iucn.org/resources/conservation-tools/iucn-red-list-threatened-species).

[11]JCNB (https://www.nwmb.com/en/2-uncategorised/83-canada-greenland-joint-commission-on-beluga-and-narwhal).

[12]MMPA (https://www.fws.gov/international/laws-treaties-agreements/us-conservation-laws/marine-mammal-protection-act.html).

NAMMCO

North Atlantic Marine Mammal Commission; regional body for cooperation on conservation, management, and study of cetaceans (whales, dolphins and porpoises) and pinnipeds (seals and walruses) in the North Atlantic Ocean[13].

Near Threatened (IUCN)

Red List designation of a species, subspecies, or "subpopulation" (as defined in the Guidelines) that has been evaluated against the Red List criteria but does not qualify for Critically Endangered, Endangered, or Vulnerable, but is close to qualifying for Vulnerable or is likely to qualify for Vulnerable in the near future.[3]

NHB

Northern Hudson Bay; in this issue, a narwhal stock that summers in Hudson Bay.

NOW

North Water Polynya called Pikialasorsuaq in Greenlandic; polynya (area of open water surrounded by sea ice) that remains open year-round between Greenland and Canada in northern Baffin Bay and extending into Smith Sound and Lancaster Sound.

Norwegian Red List

List of species considered to be at risk of going extinct in Norway. Species are generally included on the Red List because they are rare or because the number of individuals is in strong decline. Habitat fragmentation and loss also increase the risk of extinction; categories are: Regionally Extinct (RE), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Data Deficient (DD).[14]

NSR

Northern Sea Route; shipping route within the Russian EEZ, defined by Russian legislation that extends from Novaya Zemlya and along the mainland coast from the Kara Sea, Laptev Sea, and East Siberian Sea to the Bering Strait.

NWP

Northwest Passage; sea route between the Pacific and Atlantic Oceans following the coast of northern Alaska from the Bering Strait and through the Canadian Arctic Archipelago to Baffin Bay.

PBR

Potential Biological Removal; risk-averse method of assessing a stock with limited information (a recent estimate of abundance and an estimate of removals: Wade, 1998); sets a threshold number of removals below which there is little concern; provides guidance for managing removals to assure sustainability and if necessary, recovery of the stock to some desired level which under U.S. law is the "optimum sustainable population". The PBR value is not an estimate of the maximum number of individuals that can be taken sustainably each year, but rather it is seen as a safe limit—i.e., as long as removals are below the PBR, there is a high probability that the stock will recover to or remain within its optimum sustainable population size.

PBDE's

Polybrominated diphenyl ethers; chemicals that are used as flame retardants; because of their toxicity and persistence, the industrial production of some PBDE's is restricted under the Stockholm Convention, a treaty to control and phase out major persistent organic pollutants.

PCB's

Polychlorinated biphenyls; organic chlorine compounds that were widely used in electrical equipment and other applications; and are now banned by international convention (See PBDE's) but remain as persistent pollutants in many aquatic ecosystems.

Red Book of Chukotka [Russia]

Official state document that lists rare and endangered species (and subspecies) of animals, plants, and fungi in the terrestrial and marine environments within the Chukotka Autonomous Okrug, Russian Federation.[15]

Removals

Individuals removed from a population due to human activities including hunting, bycatch (incidental mortality) in fisheries, live-capture for display or research, vessel strikes, etc.

Risk Assessment Modeling

Estimates levels of risk to a population from different levels of removals; as applied to monodontid stocks in Greenland and some stocks in Canada (c.f., Witting et al., 2019), a series of abundance estimates and history of removals are used in a Bayesian framework to estimate the depletion level and the probability that the population will not decline at various levels of removal over 5 years; this information is provided to managers who can then consider risk tolerance and recovery goals in setting allowable take levels.

Risk Tolerance

In conservation, a judgment reflected in policy that indicates the degree of willingness to accept risk when making conservation decisions. For example, acceptance of a 70% probability that allowable removal levels will not cause the population to decline may be characterized as a moderate degree of risk tolerance (c.f. Witting et al., 2019).

SARA - Species At Risk Act [Canada]

Federal law passed in 2002 which came into full effect in 2004, with three main goals, to 1) prevent endan-

[13]NAMMCO (https://nammco.no/).

[14]Norwegian Red List for Species (https://www.biodiversity.no/Pages/135380/Norwegian_Red_List_for_Species).

[15]Andreev, A.V., D. I. Berman, P. Yu Gorbunov, N. E. Dokuchaev, V. S. Kononenko, B. A. Korotyaev, A. A. Kochnev, A. V. Krechmar, D. I. Litovka, Yu. M. Marusik, L. A. Prozorova, I. A. Chereshnev, F. B. Chernyavsky, and O. A. Khruleva. 2008. The Red Book (Endangered Species List) of the Chukotka Autonomous Okrug // Chukotka Dep. of Ind. & Agricult.;RAS Far Eastern Branch, Northeastern Scientific Center, Institute of Biological Problems of the North. Magadan. - Vol. 1 Animals, p. 235 (avail. at https://www.ipae.uran.ru/sites/default/files/publications/ipae/0876_2008_RedBook_ChukotAO_T1.pdf).

gered or threatened species from becoming extinct or extirpated, 2) help in the recovery of endangered, threatened and extirpated species, and 3) manage human activities to prevent species from becoming endangered or threatened; designations include Extirpated, Endangered, Threatened, Special Concern, and Not At Risk.[2]

SLE

St. Lawrence Estuary; in this issue, a beluga stock residing therein.

SI

Somerset Island; in this issue, a narwhal stock that aggregates near Somerset Island in summer.

Stock

A subunit of a biological population that is suitable for management; should be designated and managed in such a way that the population and/or species as a whole persists throughout its range; often comprises a breeding population that occupies the same regions annually.

Strategic (as Defined by MMPA [USA])

Designation of a marine mammal stock 1) for which the level of direct human-caused mortality exceeds the potential biological removal (PBR, see above) level; 2) that based on the best scientific information available, is declining and is likely to be listed as a threatened species under the ESA in the foreseeable future; or 3) that is listed as a threatened or endangered species under the ESA, or is designated as depleted under the MMPA.[12]

Struck-But-Lost (or Struck-And-Lost)

Term for instances when an animal being hunted is struck by the weapon (e.g., harpoon, rifle) but is not recovered or secured and therefore is not counted as caught or landed; also referred to as hunting loss.

Sustainable Removals

Levels of removals by hunting (or other human actions) that do not cause the stock abundance to decline.

TALC

Total Allowable Landed Catch; allowed catch level, the total allowable removals minus the estimated number of struck-but-lost.

TAT

Total Allowable Take; landed (secured) catch plus the known or estimated struck-but-lost.

Take (or Taking) (MMPA [USA])

Defined in the MMPA as "the act of hunting, killing, capture, and/or harassment of any marine mammal; or, the attempt at such."[12]

Takes (General)

Animals removed from a population by hunting (or other means).

Threatened (COSEWIC [Canada])

COSEWIC designation of a wildlife species (encompassing subspecies and "designatable units" – a term specific to SARA) that is likely to be assessed as Endangered if not enough is done to reverse the factors leading to its listing as Threatened.[7]

Threatened (ESA [USA])

ESA designation of a species, subspecies, or DPS that is likely to be listed as Endangered in the foreseeable future throughout all or a significant portion of its range.[6]

WHB

Western Hudson Bay; in this issue, a beluga stock that summers in western Hudson Bay.

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Global Review of the Conservation Status of Monodontid Stocks

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Introduction

The family Monodontidae is comprised of the narwhal, *Monodon monoceros*, and the beluga or white whale, *Delphinapterus leucas* (Rice, 1998). These two species are found in much of the Arctic and in a number of subarctic areas, generally inhabiting more coastal areas during the summer and deeper ice-covered areas in the winter. Both species are sought by indigenous subsistence hunters in several Arctic nations in their summer habitat as well as along migration routes and, in some cases, in wintering areas.

Some populations of the two species were reduced by commercial hunting for oil, meat, and skins and in the case of narwhals, the valuable tusk (Mitchell and Reeves, 1981; Reeves and Heide-Jørgensen, 1994; Heide-Jørgensen, 1994). Belugas in some areas were culled to reduce perceived competition with fisheries (Reeves and Mitchell 1984). More recently, some populations have been reduced (or further reduced) by uncontrolled subsistence hunting (Reeves and Mitchell,

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ABSTRACT—The monodontids—narwhals, Monodon monoceros, *and belugas,* Delphinapterus leucas*—are found in much of the Arctic and in some subarctic areas. They are hunted by indigenous subsistence users. In the past, some populations were substantially reduced by commercial hunting and culling; more recently, some populations have declined due to uncontrolled subsistence hunting and environmental degradation. Monodontids are impacted increasingly by human activities in the Arctic including ship and boat traffic, industrial development, icebreaking, seismic surveys, competition with fisheries, and alteration of habitat due to climate change. Since comprehensive reviews in the 1990's, substantial new information has become available on both species and on changes to their habitat as a result of human activities and climate change. Thus NAMMCO and partners undertook an updated review in 2017. The review recognized 21 extant beluga stocks, 1 extirpated beluga stock, and 12 stocks of narwhals. The available information on each stock regarding population size, depletion level, current and past removals, and trends in abundance was reviewed to determine status. Concern was expressed where the lack of information prevented reliable assessment, removals were thought to be unsustainable, or the population was deemed at risk of declining even without direct removals by hunting. Beluga stocks of greatest concern are the small stocks in Ungava Bay (possibly extirpated), Cook Inlet (ca 300), St. Lawrence Estuary (ca 900), and Cumberland Sound (ca 1,100), and the stocks with uncertainty in Eastern Hudson Bay and the Barents-Kara-Laptev Seas. Narwhal stocks of greatest concern are those in Melville Bay and East Greenland.*

1989; Hammill et al., 2004; Hobbs et al., 2015a) or hit hard by the live-capture industry (primarily for live display in zoos and oceanariums; Shpak et al., 2019). Other sources of impacts on monodontids include the noise from ship and boat traffic, industrial activities of various kinds, icebreaking, seismic surveys, competition with fisheries, and the rapid alteration of habitat as a result of climate change (Finley et al., 1990, Gordon et al., 2004; Laidre et al., 2008, 2015; Reeves et al., 2014; Norman et al., 2015).

The stocks of belugas and narwhals were reviewed by the Scientific Committee of the International Whaling Commission (IWC) in 1992 (IWC, 1993) and more thoroughly (for belugas) in 1999 (IWC, 2000). The North Atlantic Marine Mammal Commission (NAMMCO) Scientific Committee's Working Group on the Population Status of Beluga and Narwhal in the North Atlantic carried out an extensive review of beluga and narwhal stocks in the Atlantic and adjacent waters in 1999 (NAMMCO[1]).

Since 1999, much new information has become available on both species—regarding stock identity, distribution, movements, abundance, anthropogenic removals, and threats to populations. Additionally, new and newly recognized stressors have emerged, and significant changes in climate and habitat have occurred either directly or indirectly owing to increasing human activity in the Arctic as well as global climate change. Thus NAMMCO and various partner organizations and individual scientists unaffiliated with NAMMCO undertook an updated review in 2017 with the following three phases:

1) A steering committee was established with at least one member from each nation with beluga or narwhal stocks. The committee identified subject experts for each stock and requested a written review for each stock or known aggregation. These reviews included the following topics: a) stock identity—description and distribution with supporting genetic studies, telemetry data, catch locations and times, traditional knowledge, etc.; b) abundance—sighting surveys, mark-recapture data, etc.; c) anthropogenic removals by hunting (catch statistics, including struck-but-lost and under-reporting), bycatch or entanglement in fisheries, and other causes; d) population trend—historical and recent rates of decline or increase, current and maximum net reproduction rates; e) management measures to limit removals—e.g., PBR (potential biological removal)—and other methods of determining reference levels to ensure recovery and sustainability; f) habitat and other concerns; and g) national legal status of the stock.
2) The Global Review of Monodontids (GROM) workshop was held 13–16 March 2017 in Hillerød, Denmark, with monodontid experts as well as experts on genetics, environmental issues, stock assessment, and traditional knowledge. The workshop heard presentations on how stocks were defined and designated in previous monodontid reviews and on genetic methods used for stock delineation. The workshop devised an approach to assessment and determined a level of concern that accounted for the quality of information on each stock as well as its conservation status. More than 20 stocks of belugas and 12 stocks of narwhals were identified, reviewed in detail, and assessed.

   Consensus was sought on stock definitions, key points of assessment, and levels of concern. In most cases, the consensus became evident during the discussion and exchange of views among workshop participants. Where revisions or additions to a stock review were requested, the consensus was made contingent on those changes being made by the author(s). In a few cases where concerns remained or objections were made to the information provided or conclusions drawn, the majority opinion of the workshop was followed and a statement describing the concerns or objections was recorded in the discussion section of the workshop report.

   Following the stock by stock assessments, the workshop discussed global and regional issues related to the conservation of belugas and narwhals that had been raised either in the individual stock reviews or during the meeting, identified existing and emerging threats and knowledge gaps, and developed recommendations for research and cooperation.
3) Following the workshop, some of the stock reviews prepared as background information were revised in response to advice from the workshop. In some instances, this included information that was known but did not become available until after the workshop. The final workshop report, along with the revised stock reviews, was made public on the NAMMCO website in 2018 (https://nammco.no/wp-content/uploads/2018/05/report-global-review-of-monodontids-nammco-2018_after-erratum-060518_with-appendices_2.pdf).

In this paper, we summarize the current status of all beluga and narwhal stocks and the major findings and recommendations from the GROM. In a few cases, we incorporate new information that became available after the workshop. It should be noted that while a serious effort was made to provide peer-reviewed citations in support of statements made and conclusions reached, a review such as this one necessarily includes reference to gray literature (footnoted) and occasionally the opinions of subject experts. The

[1]NAMMCO. 1999. Report of the working group on the population status of beluga and narwhal in the North Atlantic. Oslo, 1-3 Mar. 1999. (avail. at http://nammco.wpengine.com/wp-content/uploads/2016/09/SC_7_4-WG-Report-1999.pdf).

Table 1.—Evidence supporting stock discrimination of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*. Y = available data support stock discrimination; + = available data provide some support for stock discrimination; N = available data do not support stock discrimination or are inconclusive; – = no data are available.

Stocks	Summer distribution	Winter distribution	Movement, behavior, or life history traits	Genetics (mtDNA)
Beluga				
1. Sakhalin-Amur	Y	+	+	Y
2. Ulbansky	Y	–	+	Y
3. Tugursky	Y	–	+	N
4. Udskaya	Y	–	+	Y
5. Shelikhov	Y	+	+	Y
6. Anadyr	Y	Y	Y	Y
7. Cook Inlet	Y	Y	Y	Y
8. Bristol Bay	Y	+	Y	Y
9. Eastern Bering Sea	Y	+	Y	Y
10. Eastern Chukchi Sea	Y	+	Y	Y
11. Eastern Beaufort Sea	Y	+	Y	Y
12. High Arctic – Baffin Bay	Y	+	+	+
13. Western Hudson Bay	Y	+	Y	+
14. James Bay	Y	Y	+	+
15. Eastern Hudson Bay	Y	+	Y	+
16. Ungava Bay	Y	+	+	+
17. Cumberland Sound	Y	Y	Y	+
18. St. Lawrence Estuary	Y	Y	+	Y
19. Southwest Greenland	–	Y	Y	–
20. Svalbard	Y	Y	Y	Y
21. Barents-Kara-Laptev Seas	+	+	–	–
22. White Sea	Y	Y	Y	+
Narwhal				
1. Somerset Island	Y	+	Y	N
2. Jones Sound	Y	+	+	Y
3. Smith Sound	Y	+	+	N
4. Admiralty Inlet	Y	+	+	N
5. Eclipse Sound	Y	+	+	N
6. Inglefield Bredning	Y	+	–	N
7. Melville Bay	Y	+	Y	N
8. Eastern Baffin Island	Y	+	+	N
9. Northern Hudson Bay	Y	Y	Y	Y
10. East Greenland	Y	Y	Y	N
11. Northeast Greenland	Y	–	–	–
12. Svalbard-NW Russian Arctic	–	–	–	–

quality as well as the content of information available to the workshop was considered in seeking to reach a consensus of the expert opinion represented at the GROM workshop.

Identification of Stocks

Various criteria were used to define stocks generally, with emphasis on how beluga and narwhal stocks have been defined in previous reviews and by current management. In general, a stock is a population unit suitable for management and stocks should be designated in such a way that with good management, the species will persist throughout its historical range (IWC, 2000). Largely, stocks are breeding populations that occupy the same regions annually. For monodontids, recurrent aggregations were considered as candidate stocks, with the practical consideration that most hunting operations target these aggregations, and in many cases the migration routes had not been determined (IWC, 2000).

In its 1999 review, the IWC Scientific Committee (IWC-SC) used an essentially ad hoc approach to determine which aggregations should be considered stocks (IWC, 2000). The IWC-SC used a variety of criteria including genetic relationships, distribution and movements, patterns of exploitation, contaminant profiles, expert opinion, and traditional knowledge. A total of 29 putative beluga stocks were identified in that review. It is unclear how the participants balanced or weighted the different types and strengths of evidence, but in many cases the available data were deemed inadequate to delineate stocks with high confidence.

The approach used by the NAMMCO Scientific Committee (NAMMCO-SC) in its review of belugas and narwhals in the North Atlantic and adjacent waters was similarly ad hoc, identifying 25 major "aggregations" of belugas and 17 of narwhals. It was acknowledged that these aggregations (summering, wintering, or migrating areas) could be "discrete, or a mixture of stocks." As a guiding principle, the NAMMCO-SC review group concluded in 1999 that it was "prudent to base putative management units on local aggregations and/or harvesting areas until more information on stock structure is available."

Research on beluga mitochondrial genetics (mtDNA) since the early 1990's has demonstrated matrilineal fidelity to summering areas (Table 1; O'Corry-Crowe et al., 1997, 2002, 2010; De March et al., 2002, 2004; De March and Postma, 2003; Meschersky et al., 2008, 2013). Aerial surveys and satellite tracking studies have made it possible to map the distribution and estimate the abundance of many of these summer aggregations (Table 2). Narwhal summer aggregations have not been distinguished using mtDNA, and there has been only limited success using other methods (Palsbøll et al., 1997; de March and Stern[2]; de March et al.[3]; Petersen et al.[4]; Watt et al.[5]), which may be due to differences in the mating systems of the two species (Kelley et al., 2015). However, in satellite tracking studies of several narwhal stocks, the tracks that continued through the fall and spring migra-

[2]de March, B. G. E., and G. Stern. 2003. Stock separation of narwhal (*Monodon monoceros*) in Canada based on organochlorine contaminants. CSAS Res. Doc. 2003/79 (avail. at http://waves-vagues.dfo-mpo.gc.ca/Library/279332.pdf).

[3]de March, B. G. E., D. A. Tenkula, and L. D. Postma. 2003. Molecular genetics of narwhal (*Monodon monoceros*) from Canada and West Greenland (1982–2001). DFO Can. Sci. Advis. Sec. Res. Doc. 2003/080, 1–19 (avail. at http://waves-vagues.dfo-mpo.gc.ca/Library/279333.pdf).

[4]Petersen, S. D., D. Tenkula, and S. H. Ferguson. 2011. Population genetic structure of narwhal (*Monodon monoceros*). DFO Can. Sci. Advis. Sec. Res. Doc. 2011/021. vi + 20 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/Library/343698.pdf).

[5]Watt, C. A., S. H. Ferguson, A. Fisk, and M. P. Heide-Jørgensen. 2012. Using stable isotope analysis as a tool for narwhal (*Mondon monoceros*) stock delineation. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/057. iv + 29 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/Library/279333.pdf).

Table 2.—Summary of information provided for the status review.

	Stock/Summer Aggregation	Movements (e.g. winter, summer migrations, to/from location)	Abundance (Year) a: availability bias; p: perception bias	Trend	Removals	Threats and/or concerns	National legal status
Belugas							
1	Sakhalin-Amur	Summer in Sakhalinsky Bay and Amur estuary, winter in northern and central Okhotsk Sea (offshore)	3,954 (CV = 0.24) (average for 2009, 2010a, 2010b); corrected for a; Shpak and Glazov (2013)	Unknown	Recently above PBR, current allowable take set close to PBR	Pollution/infectious agents from Amur River, competition with fisheries, ship traffic, noise	None
2	Ulbansky	Summer in Ulbansky Bay and river estuaries, winter movements unknown but presumably similar to Sakhalin-Amur	2,334 (from direct count, corrected for a) (2010);Shpak and Glazov (2013)	Unknown	No direct removals	Fishery interactions, potential pollution risk from mining activities	None
3	Tugursky	Summer in Tugursky Bay, winter movements unknown but presumably, similar to Sakhalin-Amur	1,506 (from direct count, corrected for a) (2010); Shpak and Glazov (2013)	Unknown	No direct removals	Fisheries, mining activities/pollution, discharge of human and livestock waste	None
4	Udskaya	Summer in Udskaya Bay and river estuaries, found along south coast at ice formation, winter in areas unknown but presumably similar to Sakhalin-Amur	2,464 (from direct count, corrected for a) (2010); Shpak and Glazov (2013)	Unknown	No direct removals	Fisheries, mining activities/pollution, discharge of human and livestock waste, ship traffic/noise, leaks during diesel fuel transit	None
5	Shelikhov	Summer in Gizhiginskaya and Penzhinskaya bays of Shelikhov Bay in river estuaries and along west coast of Kamchatka Peninsula, presumably winter along ice edge in Shelikhov Bay and along Kamchatka	2,666 (from direct count, corrected for a) (2010); Shpak and Glazov (2013)	Unknown	No direct removals	Decreasing sea ice, future development in the area	None
6	Anadyr	Summer and autumn in Anadyr estuary, winter in western Bering Sea	Unknown but expert opinion indicates ca. 3,000 (Litovka, 2002)	Unknown but expert opinion that it is stable	Small numbers harvested	Competition from fisheries, ship traffic, reduced sea ice	None
7	Cook Inlet	Summer in river mouths in upper inlet, likely remain in upper inlet year-round (range reduction from historical)	279 (CV = 0.06) (2018); corrected for a and p; Shelden and Wade (text fn 22)	Declining	Reduced to 1-2/yr in 2000, prohibited since 2005	Very small numbers, decreasing trend, cumulative impacts (of competition from fisheries, industrial development, ship traffic, climate change, sewage discharge, etc.)	U.S. ESA "Endangered" (2008)
8	Bristol Bay	Summer in Nushagak and Kvichak bays and tributaries, winter in northern and eastern Bristol Bay	Aerial survey: 2,040 (CV=0.22, 95% CI: 1,541-2,702) (2016); corrected for a; genetic mark-recapture: 1,928 (95% CI: 1,611–2,337); Citta et al. (2019)	Stable	~ 20-25/yr, stable in recent years, below PBR	Climate warming, loss of sea ice, competition from large fishery for salmon, development plans (gold, Pebble Mine)	None
9	Eastern Bering Sea	Summer in Norton Sound and in or near the Yukon River delta; winter south in eastern Bering Sea to Bristol Bay	9,242 (CV = 0.12) (2017); corrected for a; Lowry et al. (2019)	Unknown	Average 190/yr landed w/ struck-but-lost , 215/yr, above PBR of 201 and under-reporting is not estimated.	Fisheries (competition, not bycatch), declining populations of salmon	None
10	Eastern Chukchi Sea	Summer in Beaufort Sea and Arctic Ocean to as far north as lat. 81° N, particularly along the shelf break; fall/winter move south to Bering Sea; winter between St. Lawrence Island, U.S., and Chukotka Peninsula, Russia	20,675 (CV = 0.66) (2012); corrected for a and p; Lowry et al. (2017a)	Unknown	Ca. 50/yr, below PBR	Ship traffic, oil and gas development, sea ice changes	None
11	Eastern Beaufort Sea	Summer in Beaufort Sea, winter in Bering Sea	39,258 (1992); corrected for a; Duval 1993	Unknown	Ca. 166/yr, below PBR	Summer tourism, ship traffic, ecosystem changes (climate change)	Canada: "Not at Risk" (COSEWIC, 2015)
12	High Arctic-Baffin Bay	Summer in estuaries, inlets, and small bays along and around Somerset Island in Canadian Arctic Archipelago; late summer/fall and spring migration through Lancaster Sound; some overwinter in North Water polynya, some off West Greenland	21,213 (95% CI 10,985–32,619) (1996); corrected for a,p; Innes et al. (2002)	Likely stable (but old abundance estimate); relative abundance in West Greenland is increasing	Ca. 400/yr (Canada + Greenland), considered sustainable	Loss of sea ice, ship traffic and icebreaking	Canada: "Special Concern" (COSEWIC, 2004)

Table Continued

Table 2.—*Continued.*

	Stock/Summer Aggregation	Movements (e.g. winter, summer migrations, to/from location)	Abundance (Year) a: availability bias; p: perception bias	Trend	Removals	Threats and/or concerns	National legal status
13	Western Hudson Bay	Summer concentrations in Seal, Churchill, and Nelson River estuaries, found along entire WHB coast; winter in Hudson Strait (overlap with Eastern Hudson Bay stock)	54,473 (CV = 0.098; CI: 44,988–65,957) (2015); corrected for a; Matthews et al. (2017)	Stable	Average 503/yr, below PBR	Icebreaking in Hudson Strait	None
14	James Bay	Remain in James Bay year-round	10,615 (CV = 0.25) (2015); corrected for a; Gosselin et al. (text fn 34)	Unknown; possibly increasing, uncertainty regarding abundance estimates	Limited (ca. 10/yr)	Hydroelectric development	None
15	Eastern Hudson Bay	Summer in eastern Hudson Bay, winter in Hudson Strait and Labrador Sea (overlap with Western Hudson Bay stock)	Aerial survey: 3,819 (CV=0.43) (2015) corrected for a; Gosselin et al. (text fn 34). Modeling: 3,443 (95% CI: 2014-5471) (2016); Hammill et al. (2017)	Stable	Ca. 63/yr	Uncertainties around abundance estimates, stock structure (and stock identity of removals), habitat issues (ship traffic, icebreaking, hydroelectric development)	Assessed as "Endangered" (COSEWIC, 2004) but not legally listed
16	Ungava Bay	Previous summer aggregation in S. Ungava Bay, winter unknown	Modeling: 32 (95% CI: 0-94) (2008); Doniol-Valcroze and Hammill (text fn 39)	Unknown; possibly extirpated	Previous removals	Possibly extirpated	Assessed as "Endangered" (COSEWIC, 2004) but not legally listed
17	Cumberland Sound	Remain within Cumberland Sound, concentrate in Clearwater Fiord in summer	1,151 (CV = 0.214, 95% CI: 761–1744) (2014); corrected for a; Marcoux et al. (text fn 42)	Declining	Removals higher than PBR	Hunting removals, ecosystem changes (diet shift), stress (possibly due to anthropogenic noise, cumulative impacts)	"Threatened" (COSEWIC, 2004; SARA, 2017)
18	St. Lawrence Estuary	Limited to northwestern Gulf of St. Lawrence and estuary (reduced from historical range)	Modeling: 889 (95% CI: 672–1167) (2012); Mosnier et al. (2015)	Declining (-1%/yr)	No direct removals since 1979	Vessel traffic, disturbance (whale-watching), contaminants, environmental changes	"Endangered" (COSEWIC, 2014; SARA, 2016)
19	Southwest Greenland	N/A	Extinct	N/A	Likely driven to extinction by overharvest	Extinct	None
20	Svalbard	Coastal around Svalbard in summer, further offshore in winter	Unknown	Unknown	No direct removals	Changes in sea ice, pollution, development	Protected since 1960s
21	Barents-Kara-Laptev Seas	Summer in waters of archipelagos (Franz Josef Land), in estuaries of large rivers, along mainland coast; movements unknown; very few observations in winter, mostly in Kara Sea	Unknown (widespread in low density), probably depleted by commercial whaling	Unknown	None since ca. 1990	Uncertainty around stock structure (likely several stocks), may have been greatly overexploited in the past, considerable new development and ship traffic, military activity	None
22	White Sea	Summer aggregations mostly in 3 large bays, late summer distribution more scattered in and near White Sea; winter in White Sea, mostly in central part (limited data)	5,593 (CV = 0.135) (2011); not corrected for a; (Solovyev et al., 2015)	Likely stable	Total allowable take 50, removals limited to live-captures (several whales, not every year)	Uncertainty around stock structure (could be several stocks), habitat issues (major shipping route through White Sea, pollution from oil storage and tankers, river discharge from northern Dvina River)	None
Narwhals							
1	Somerset Island	Summer around Somerset Island, distributed more widely in late summer (follow ice as it breaks up), fall migration into central Baffin Bay for overwintering	49,768 (CV = 0.20) (2013); corrected for a and p; Doniol-Valcroze et al. (text fn 65)	Possibly increasing	Considerable numbers (Canada and Greenland) but considered sustainable	Loss of sea ice, icebreaking, and development in some areas	"Special Concern" (COSEWIC, 2004) but not legally listed
2	Jones Sound	Summer in Jones Sound, wintering area unknown	12,694 (CV = 0.33) (2013); corrected for a and p; Doniol-Valcroze et al. (text fn 65)	Unknown	Low numbers, considered sustainable	Icebreaking, loss of sea ice, potential development	"Special Concern" (COSEWIC, 2004) but not legally listed
3	Smith Sound	Summer in Smith Sound, wintering area unknown	16,360 (CV = 0.65) (2013); corrected for a and p; Doniol-Valcroze et al. (text fn 65)	Unknown	Few (if any)	Icebreaking, loss of sea ice, potential development	"Special Concern" (COSEWIC, 2004) but not legally listed

Table Continued

Table 2.—*Continued.*

	Stock/Summer Aggregation	Movements (e.g. winter, summer migrations, to/from location)	Abundance (Year) a: availability bias; p: perception bias	Trend	Removals	Threats and/or concerns	National legal status
4	Admiralty Inlet	Summer in Admiralty Inlet, winter in Baffin Bay	35,043 (CV = 0.42) (2013); corrected for a and p; Doniol-Valcroze et al. (text fn 65)	Stable	Considerable numbers (Canada and Greenland) but considered sustainable	Ship traffic, icebreaking	"Special Concern" (COSEWIC, 2004) but not legally listed
5	Eclipse Sound	Summer in Eclipse Sound, winter in central Baffin Bay	10,489 (CV = 0.24) (2013) corrected for a and p; Doniol-Valcroze et al. (text fn 65)	Unknown	Considerable numbers in Pond Inlet (Canada) and other areas along migration route	Uncertainty about abundance estimates and stock identify (vs Admiralty Inlet stock); ship traffic, particularly related to the Baffinland-Mary River iron mine; tourism	"Special Concern" (COSEWIC, 2004) but not legally listed
6	Inglefield Bredning	Summer in Inglefield Bredning, wintering area unknown but narwhals seen in the North Water polynya in winter may be from this stock	8,368 (CV = 0.25, CI: 5,209–13,422) (2007); corrected for a and p; Heide-Jørgensen et al. (2010).	Stable	Considerable numbers (Greenland) but considered sustainable	Loss of sea ice, seismic surveys (in parts of non-summer range), ship traffic, icebreaking, increased halibut fishing in summering area (competition for prey)	"Special Concern" (COSEWIC, 2004) but not legally listed
7	Melville Bay	Summer in Melville Bay, winter in central Baffin Bay	3,091 (CV = 0.50; 95% CI 1,228 to 7,783) (2014); corrected for a and p; Hansen et al. (text fn 72)	Stable	Above quota advice	Overharvested, seismic surveys, icebreaking (winter), halibut fishing	None
8	Eastern Baffin Island	Summer in fjords along eastern Baffin Island, wintering area(s) unknown but assumed to be in Baffin Bay	17,555 (CV = 0.35) (2013); corrected for a and p; Doniol-Valcroze et al. (text fn 65)	Stable?	Hunted by various communities, increasing since 1970s but still considered sustainable	Uncertainty around abundance estimates, stock structure (could be several stocks), and movements; habitat loss related to climate change, icebreaking	"Special Concern" (COSEWIC, 2004) but not legally listed
9	Northern Hudson Bay	Summer in northwestern Hudson Bay, winter in eastern Hudson Strait	12,485 (CV = 0.26) (2011); corrected for a and p; Asselin et al. (text fn 74)	Stable?	Ca: 83/yr, likely sustainable	Loss of sea ice, proposed development in area, ship traffic	"Special Concern" (COSEWIC, 2004) but not legally listed
10	East Greenland	Summer in Scoresby Sound, Tasiilaq Fjord, and Kangerlussuaq Fjord, elsewhere in fall/winter, smaller wintering range than that of Baffin Bay narwhals	702 (CV = 0.33) (2016); NAMMCO (text fn 78)	Declining	Recently overharvested, advice for reduction in quotas	Recent overharvest; climate change—warmer temperatures, loss of sea ice and tidewater glaciers may mean loss of habitat; new species in area—may mean competition for prey, exposure to novel diseases	None
11	Northeast Greenland	No information	1,395 narwhals (CV=0.33) in Dove Bay (2017) and 2,908 (CV=0.30) in the Greenland Sea (2017) (Reeves and Lee, 2020)	Unknown	None	Loss of sea ice and tidewater glaciers may mean loss of habitat; new species in the area may mean competition for prey, exposure to novel diseases; future development	None
12	Svalbard-Northwest Russian Arctic	Unknown	Unknown through most of the range; 837 (CV=0.50) (2015) north of Svalbard (Vacquié-Garcia et al., 2017)	Unknown	None	Lack of data (abundance, movements, etc.), climate change, development, military activity	Protected in Norway and Russia

tions showed the animals returning to the aggregation of origin in most cases (Heide-Jørgensen et al., 2003a; Dietz et al., 2008; Westdal et al., 2010; Watt et al.[6]), and this supports the assumption that narwhals are similar to belugas in exhibiting fidelity to summering areas.

For many of the summer aggregations of both narwhals and belugas, migration routes have been determined and therefore individuals seen in other locations and seasons can be related back to one or more of the summer aggregations. As with belugas, most of the known summer aggregations of narwhals have been surveyed at least once since the last global or large-scale review. Thus, the GROM chose to consider recurrent summer aggregations of belugas or narwhals as potential stocks and then considered other data and lines of reasoning to determine which aggregations should be considered as separate stocks and which should be lumped together as a single stock (Table 1). It may prove necessary to change the lists of stocks in future reviews as more information becomes available.

Other Aggregations and Sightings

Reports of regular aggregations in other seasons were generally related to one or more of the known summer aggregations by reference to movement or genetics data, and thus they were not considered separate stocks. Also, small numbers of both species have been observed outside what is considered the normal range of any recognized stock or population. In areas where reliable observers have frequently been present, the occasional sightings of individuals or only a few monodontids were regarded as extralimital and not particularly significant as they were not seen to represent recurrent aggregations. It was noted, however, that if observations were to become regular in one of these areas, this could signify actual shifts or expansions in the species' distribution. Areas rarely visited by humans, where observation effort was insufficient to document recurrent aggregations but some sightings have been reported, were sometimes considered as potentially part of the seasonal distribution of a stock.

Stocks

The GROM identified 21 stocks of belugas and 12 stocks of narwhals (Table 1). Summer distribution as determined by local knowledge, tagging studies, and aerial surveys was considered sufficient, in most cases, to determine geographical separation of stocks (Fig. 1, 2; Table 1). In some areas where potential beluga stocks were in close proximity, the results of mtDNA analyses were used to decide whether they should be lumped or split. Potential narwhal stocks could not be separated using differences in mtDNA, making it necessary to rely principally on tracking data when potential stocks were in close proximity. The GROM generally followed what was regarded as a conservative (i.e., risk-averse) approach (from a conservation perspective) and chose to split such stocks.

Previous global reviews that focused on, or included, monodontids (IWC, 1993, 2000; Laidre et al., 2015; CAFF, 2017) recognized different numbers of stocks. To clarify and justify differences between the 21 stocks of belugas and 12 stocks of narwhals identified in this review, an attempt was made to explain the rationale for lumping or splitting previously recognized stocks (Table 3). Rapid environmental change in the Arctic and sub-Arctic may influence the distributions and movements of all monodontid stocks, which means that it will be important to reevaluate some of the conclusions and assumptions regarding stock identity made in this and previous reports during future reviews.

Summaries of Individual Stocks

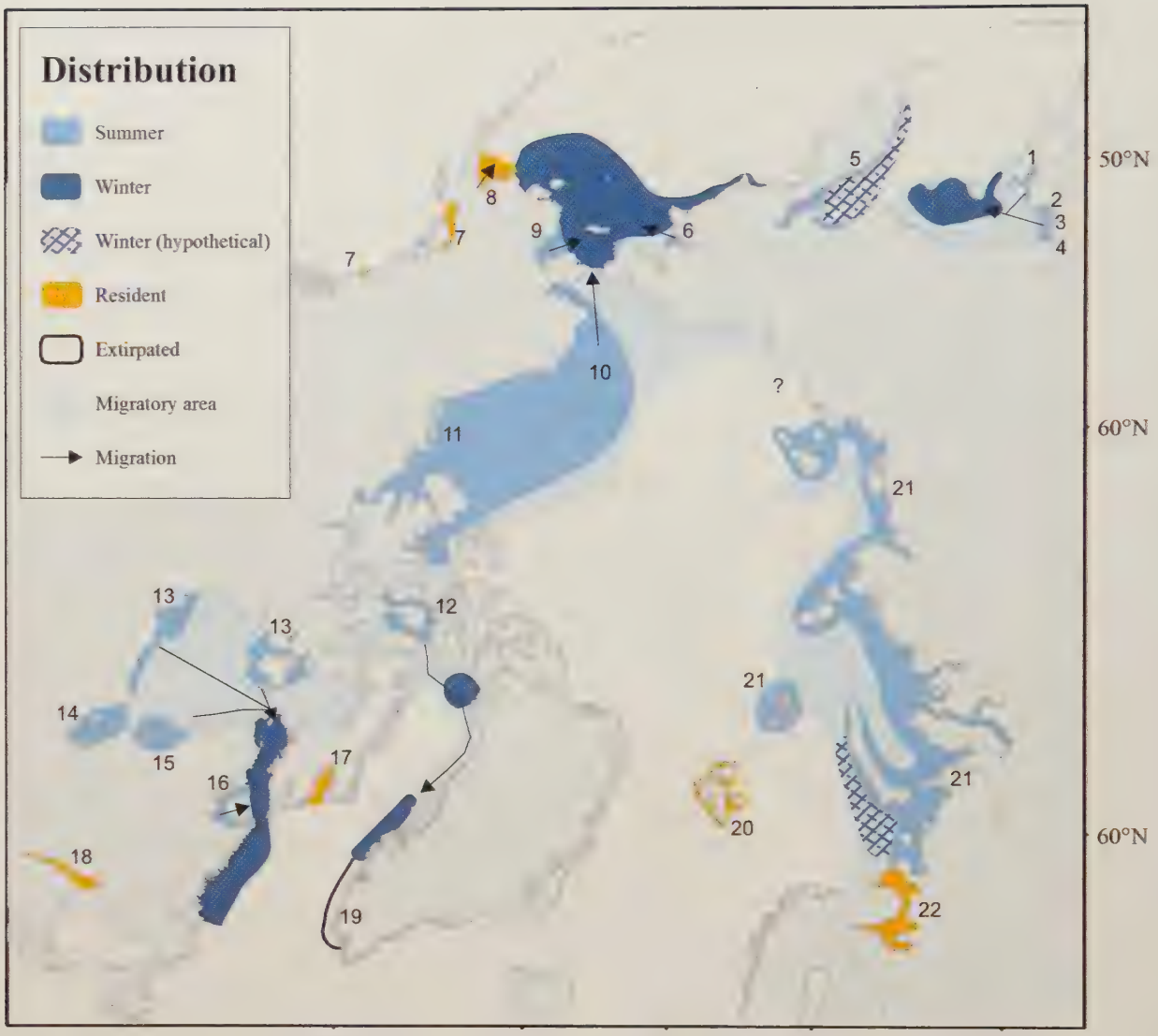
The summaries provided by researchers for each stock included a description of the stock, research used to determine distribution, abundance, and trend, data on removals and other sources of mortality, information on management, assessment of the "sustainability" of any hunting removals, a discussion of other threats to the stock, or an indication that the requested information was not available. During the workshop, we considered several questions including: 1) how well was the stock's distribution known; 2) was abundance estimated; 3) was the trend estimated; 4) were removals documented; 5) was the stock depleted; 6) were the known removals sustainable and if the stock was depleted, were removals low enough to allow recovery; and 7) what other threats were known for the stock and what was their impact?

Distribution, Abundance, and Trends

Distribution and abundance for most stocks were known from aerial surveys of the summer ranges (Table 2). In a few cases, when no survey data were available, expert opinion or traditional knowledge was taken into account. Estimates of abundance provided in the stock summaries were not reviewed and discussed in detail except where unusual methods were used; questions were raised concerning completeness of coverage, precision, or methods of correction for missed animals; or a basis was needed for evaluating expert opinion or traditional knowledge. Where two or more abundance estimates were available for a stock, a crude assessment of trend was sometimes possible, while recognizing that three or more comparable estimates are generally needed for confident conclusions concerning trends.

When survey data were used to estimate trend, the workshop considered whether the survey methods and coverage were comparable. It was emphasized that abundance estimates based on surveys (rather than solely on ex-

[6]Watt, C. A., J. Orr, B. LeBlanc, P. Richard, and S. H. Ferguson. 2012. Satellite tracking of narwhals (*Monodon monoceros*) from Admiralty Inlet (2009) and Eclipse Sound (2010–2011). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/046. iii + 17 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/Library/347232.pdf).



Beluga Stocks

Pacific Arctic/sub-Arctic

1) Sakhalin-Amur
2) Ulbansky
3) Tugursky
4) Udskaya
5) Shelikhov
6) Anadyr
7) Cook Inlet
8) Bristol Bay
9) Eastern Bering Sea
10) Eastern Chukchi Sea
11) Eastern Beaufort Sea

Atlantic Arctic/sub-Arctic

12) Eastern High Arctic-Baffin Bay
13) Western Hudson Bay
14) James Bay
15) Eastern Hudson Bay
16) Ungava Bay
17) Cumberland Sound
18) St. Lawrence Estuary
19) Southwest Greenland
20) Svalbard
21) Barents-Kara-Laptev Seas
22) White Sea

Figure 1.—Beluga stocks recognized by the Global Review of Monodontids. Stocks are identified by their summering grounds. Ranges of stocks that migrate are differentiated into summer areas (mid-blue), migration areas (light blue), and known winter grounds (dark blue) or hypothetical winter grounds (dark blue check); arrows show direction of fall migration. Ranges of stocks residing year-round in the same area are orange. Winter areas are not shown for the belugas in the Kara and Laptev Seas due to lack of information.

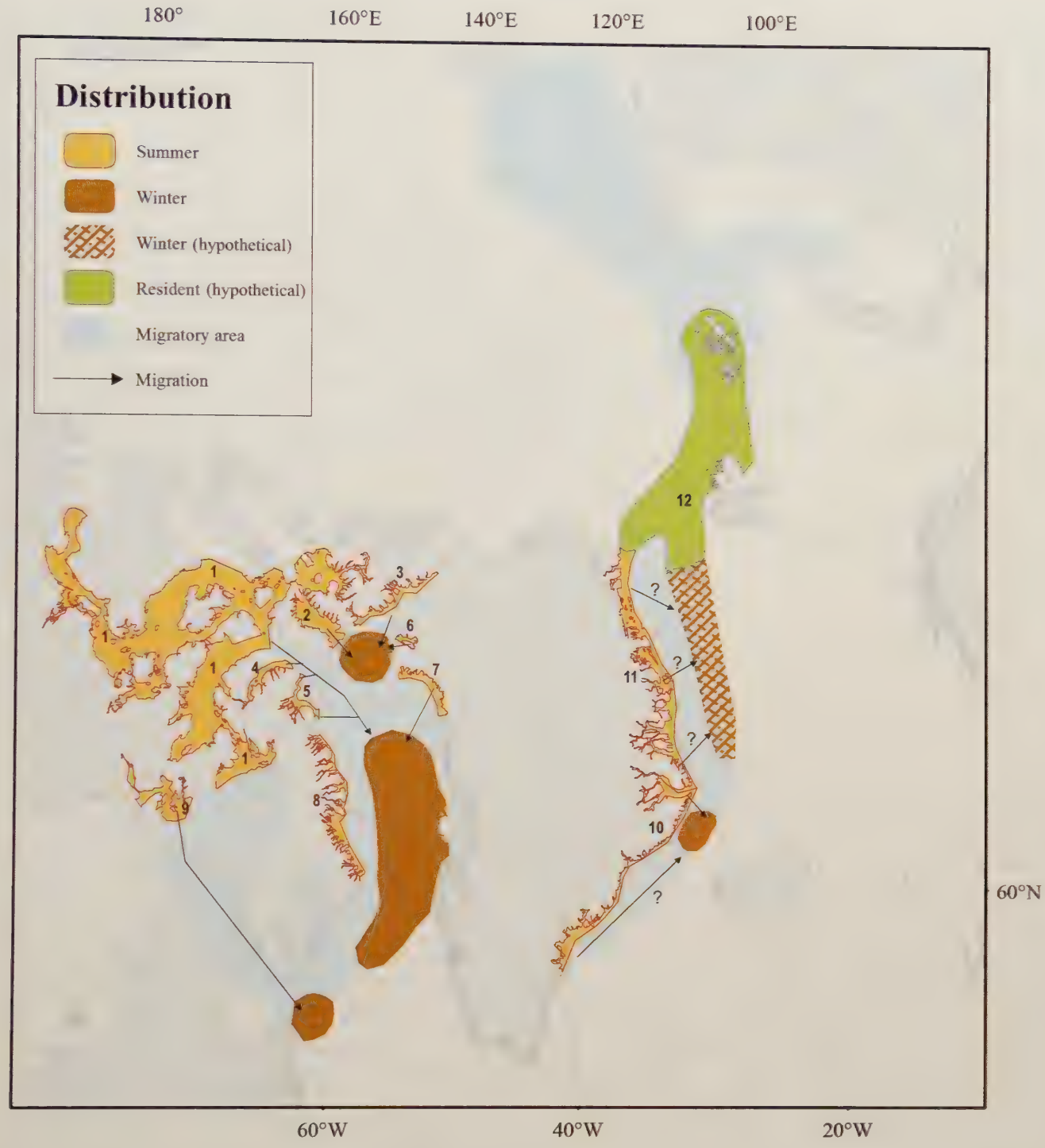


Figure 2.—Narwhal stocks recognized by the Global Review of Monodontids. Stocks are identified by their summering grounds. Ranges of stocks are differentiated into summer areas (tan), migration areas (light blue), and known winter grounds (brown) or assumed winter grounds (brown check), arrows show direction of fall migration.

Table 3.—Status of beluga and narwhal stocks. The global review took into account population size and trend, quality of data available, sustainability of removals, and habitat concerns. Trend symbols are n/a = not applicable, ↘ = declining, ↔ = stable, ↗ = increasing, ↗ ↔ = increasing or stable, ? = unknown, and ? along with a trend symbol = uncertainty in the trend. The statuses (i.e., levels of concern) are comparative to other beluga stocks and narwhal stocks, respectively, and are listed as 1 = highest concern, 2 = moderate concern, 3 = lowest concern. More information on abundance, stock identity, etc. can be found in Table 2.

Stock/location	Trend	Status	Comments on status
Beluga			
Southwest Greenland	n/a	Extinct	Likely driven to extinction more than 80 years ago
Ungava Bay	?	1	Possibly extirpated
Cook Inlet	↘	1	Very small stock (ca 300), decreasing trend, multiple known or potential threats, cumulative impacts
St. Lawrence Estuary	↘	1	Small stock (ca 900), decreasing trend, multiple known or potential threats, cumulative impacts
Cumberland Sound	↘	1	Small stock (ca 1,100), likely decreasing trend, likely overharvest
Eastern Hudson Bay		1/2[1]	Uncertainty concerning abundance, stock structure, and sustainability of removals; habitat concerns (icebreaking, hydroelectric dam)
Barents-Kara-Laptev Seas	?	1/2[1]	Data deficient (unknown size, trend, stock structure, likely several stocks), high past removals, rapidly changing habitat
Svalbard	?	2	Data deficient (unknown size and trend) but protected
Sakhalin-Amur	?	2	Unknown trend in abundance, recent removals (live-capture) exceed PBR, habitat concerns (large and increasing fisheries, pollution)
Ulbansky	?	2	Unknown trend, no direct removals, some concerns about fishing and potential pollution from mine development
Tugursky	?	2	Unknown trend in abundance, low numbers of removals, habitat concerns (fishing and pollution)
Udskaya	?	2	Unknown trend in abundance, low numbers of removals, habitat concerns (fishing, ship traffic, pollution)
Anadyr Gulf	↔	2	Data deficient (uncertain abundance, appears stable based on expert opinion), concerns over ship traffic
White Sea	↔	2	Data deficient (uncertainty around stock structure, could be several stocks), low numbers of removals (live-capture), habitat concerns (ship traffic, pollution)
Eastern Bering Sea	?	2	Outdated abundance estimate (from 2000), harvest exceeds PBR and may be underestimated due to limited struck-but-lost reporting and possible non-reporting of takes
Sheiikhov	?	3	Unknown trend in abundance, zero to low numbers of removals, some concerns about fishing and habitat loss due to climate change
Bristol Bay	↗ ↔	3	Although not a large stock, it is data-rich (reliable abundance estimates, likely stable or increasing, reliable data on sustainability of removals, etc.)
James Bay	?	3	
Eastern Chukchi Sea	?	3	Large stock with relatively low harvest level
Eastern High Arctic-Baffin Bay	↔	3	
Eastern Beaufort Sea	?	3	
Western Hudson Bay	↔	3	May be several stocks but less of a concern because of high abundance
Narwhal			
Melville Bay	↔	1	Small stock, overharvest
East Greenland	↘	1	Low abundance, data deficient, possibly several stocks, overharvest, climate change-related habitat concerns
Eastern Baffin Island	↔?	2	Data deficient (stock structure, movements), low removals but likely several stocks
Eclipse Sound	?	2	May be part of Admiralty Inlet stock, concerns about icebreaking/shipping related to mining projects
Svalbard / NW Russian Arctic	?	2	Data deficient (abundance, stock structure), likely several stocks, protected
Northeast Greenland	?	2	Data deficient (abundance, stock structure), likely several stocks, climate change related concerns, protected
Inglefield Bredning	↔	3	Small-medium sized stock with low removals, general habitat concerns related to climate change, future development
Jones Sound	?	3	Medium sized stock with low removals, general habitat concerns related to climate change, future development
Smith Sound	?	3	Medium sized stock with few or no removals, general habitat concerns related to climate change, future development
Northern Hudson Bay	↔	3	Medium sized stock, removals sustainable but concerns regarding climate warming and loss of sea ice and increasing human activity (mining, shipping)
Admiralty Inlet	↔	3	Large stock, stable trend, may be connected to Eclipse Sound stock, sustainable removals, some concerns regarding icebreaking/shipping
Somerset Island	↗?	3	Large stock, likely increasing, removals sustainable, general habitat concerns related to climate change, future development

[1]Participants were unable to reach consensus. See Eastern Hudson Bay and Barents-Kara-Laptev Seas for discussions.

pert opinion or traditional knowledge) are required to determine status whenever the monodontid stock is exploited directly or there are concerns over other threats (known or plausible) to the population. Timeliness of an abundance estimate was also considered when determining status—estimates based on survey data within the last 5 years were preferred. Older estimates, while useful, left greater uncertainty concerning the current size of the stock

History of Removals

Removals by hunting, live-captures for display or research, and in some cases other human causes of mortality/removal were documented (Table 2). In a few stocks with long monitoring or management histories, the record of removals extended back for 20 or more years and included estimates of the number of animals struck-but-lost and of unreported takes. In a few stocks, little or no information on numbers or types of removals was available, and it was necessary to rely on the opinion of subject experts.

Sustainability of Removals

An important consideration to determine the status of a stock and hence to manage its conservation is the likelihood that rates of anthropogenic removals (e.g., by hunting, live-capture, or entanglement in fishing gear) are sustainable. The workshop did not develop a formal definition of sustainability but used a working definition that sustainable removals would not cause the stock to decline. For stocks that were thought to be depleted, the workshop also considered whether the takes were low enough to allow recovery but did not include this in the determination of sustainability.

The GROM acknowledged that a number of approaches have been used to assess sustainability and noted that all of the approaches used to date depend on knowing something about annual removals (preferably an estimate with associated uncertainty, or at least an upper bound), abundance (preferably an estimate with associated uncertainty, or at least a lower bound), and some understanding of how much the population would grow if there were no removals. Other information

that is available, such as a series of abundance estimates or an estimate of trend, estimates of struck-but-lost and under-reporting of removals, age and sex structure of the removals, and the history of previous removals can be used to improve the assessment.

Risk tolerance on the part of management, i.e., the willingness to accept given levels of probability that removals are sustainable, often varies according to the type of removals being considered, as well as the information that is available. For example, management bodies may be willing to accept a higher level of risk (to the animal population) when the removals are part of a well-managed and well-documented subsistence harvest that will be evaluated every few years than when they are incidental to commercial fishing or industrial development where removals (and sub-lethal impacts) are not well-documented.

Common scientific approaches to assessment of sustainability include both a definition of sustainability and a level of risk tolerance. The two methods used in most of the stock reviews provided to the GROM were risk assessment modeling, in which risk levels are estimated directly for different levels of removals, and Potential Biological Removal (PBR) (Wade, 1998), which sets a threshold number of removals below which there is little concern (details below). The modeling approach requires more biological data whereas the PBR approach is useful for data-poor situations. Both methods use recent abundance estimates and estimated removal levels and can account for changes in distribution and seasonal movements. Local knowledge has value as both a historical record and a source of current observations of population trends. Local knowledge and feedback from hunters are often the first description of a stock and the first indication that its behavior (including trends in abundance) or habitat has changed.

Risk assessment modeling, as applied to monodontid stocks in Greenland and some stocks in Canada (Witting et al., 2019), uses a series of abundance estimates and history of removals in a Bayesian framework to estimate the depletion level and the probability that the population will not decline at various levels of removals over five years. This information is provided to managers who can then consider risk tolerance and recovery goals in setting allowable take levels.

PBR was developed in the United States to provide a risk-averse method of assessing a stock with limited information (a recent estimate of abundance and an estimate of removals: Wade, 1998). The assessment provides guidance for managing removals to assure sustainability and, if necessary, recovery of the stock to some desired or "safe" level ("optimum sustainable population" under U.S. law). The PBR, as defined in the U.S. Marine Mammal Protection Act, is calculated as,

$$PBR = N_{min} * 0.5 * R_{max} * F_R,$$

where N_{min} is a conservative estimate of population size, R_{max} is the maximum potential rate of population increase (unknown for monodontids and assumed to be 0.04, the default for cetaceans), and F_R is a recovery factor that varies between 0.1 and 1.0 depending on the stock's conservation status—e.g., from severely depleted (0.1) to recovered and not at risk (1.0). When an abundance estimate (N) with a coefficient of variation (CV) is available, N_{min} is calculated using the 20th-percentile (z=-0.842) of the lognormal distribution as,

$$N_{min} = N*\exp(-0.842*[\ln(1+CV(N)^2)]^{1/2}).$$

In the formula above, N_{min} is calculated from the abundance estimate. However, in cases where only direct counts or estimates derived from surface density without correcting for submerged animals are available, these may be used directly. Many of the stock summaries provided as background to the GROM included PBR calculations as guidance to managers and as a precautionary way of assessing the sustainability of removals by hunting. It is important to bear in mind, however, that the PBR formula uses a relatively simplistic approach and was originally developed specifically to provide guidance for managing marine mammal bycatch in commercial fisheries. The PBR level for a given stock is set to be precautionary (risk-averse) and to allow the stock to return to, or to stay at or above, its optimum sustainable population size. The emphasis is on recovery of depleted stocks and prevention of significant declines of healthy stocks. Thus, the PBR value is not an estimate of the maximum number of individuals that can be taken sustainably each year, but rather it is seen as a "safe" limit—i.e., as long as removals are below the PBR, they should be sustainable and not deplete the stock.

In a few of the stock summaries, a PBR calculation was provided using data that were outdated (e.g., an abundance estimate from data older than 5 years) and/or the known or estimated removals exceeded the PBR level. In such cases, when no other analysis was provided, the workshop relied on other types data to make a non-rigorous assessment of sustainability, making sure to document the deliberations in the GROM final report.

Scales of "Concern"

For each of the stocks, the workshop assigned a level of "concern" relative to other stocks within the species and between the two species. The scale was 1) most concern, 2) moderate concern, and 3) least concern; notes are provided in Table 3 and in the stock summaries to explain the basis for these assignments of concern level. The higher levels of concern resulted from a lack of confidence that removal levels are sustainable, the possibility that environmental or habitat issues are affecting the stock, or a general lack of reliable information about the stock.

Belugas

Belugas have a discontinuous circumpolar distribution throughout the Arctic and sub-Arctic (Fig. 1). They usually exhibit some level of site fidelity, returning to and inhabiting the same summer and winter areas year after year (Caron et al., 1990; Bren-

nin et al., 1997; Brown Gladden et al., 1997; De March et al., 2004). Most belugas are migratory, moving seasonally between separate summer and winter areas. However, some smaller populations do not undertake long-distance migrations and reside year-round in specific regions using summer and winter areas that overlap (e.g., Cook Inlet, Cumberland Sound, St. Lawrence Estuary).

The IUCN Red List classifies the beluga at the species level as Least Concern (Lowry et al.[7]); however, the rationale within the assessment documentation notes that some subpopulations (i.e., stocks) warrant separate assessment. One such subpopulation in Cook Inlet is already red-listed as Critically Endangered (Lowry et al.[8]).

As noted above, belugas are occasionally sighted outside of the recognized stock areas. There are occasional reports of sightings and catches of belugas in East Greenland, usually in the vicinity of Tasiilaq. The few individuals that occur in East Greenland are thought to belong to the population around Svalbard, the nearest stock geographically, and may represent an extension of the range of that stock.

Similarly, belugas (usually lone individuals) are known to wander into waters of the eastern United States (as far south as New Jersey) (Reeves and Katona, 1980; Cervenka[9]) and into European waters to as far south as northeastern England and the Baltic Sea (Sea Watch Foundation[10]). The GROM recognized 21 extant stocks, plus one stock, Southwest Greenland, that is known to be extirpated (Table 1). The beluga stocks recognized at the workshop as well as a comparison with the stocks listed in previous reviews are presented in Table 4.

Overview of Beluga Stocks

Many of the beluga stock designations in the 1999 IWC review (IWC, 2000) have been supported by research since 1999 on genetics, movements, and summer distribution, and they remain unchanged (Table 4). The designations were changed in a few areas. Belugas in the Okhotsk Sea have received considerable attention in the last decade, with much of the research effort directed toward determining sustainable levels of removals from the Sakhalin-Amur River area for live display (Shpak and Glazov, 2013). Research has included aerial surveys to determine distribution and abundance, biopsy sampling for genetic analysis, and capture and temporary restraint for health assessment and satellite tag attachment.

The results to date support the continued designation of Sakhalin-Amur River and Shelikhov Bay stocks (IWC, 2000). However, the former Shantar Bay stock (IWC, 2000) was split into three stocks based on the observed geographical separation of belugas during the summer in Ulbansky Bay, Tugursky Bay, and Udskaya Bay. This separation was partially supported by mtDNA analyses (Table 4).

The former Beaufort Sea stock (IWC, 2000) was changed to eastern Beaufort Sea stock in recognition that the belugas in the western Beaufort Sea during the summer belong to the eastern Chukchi Sea stock (Hauser et al., 2014). The 1999 IWC review had designated a West Chukchi Sea-Eastern East Siberian Sea stock, but the GROM reviewed the supporting data and concluded that the seasonal presence of belugas in that region was consistent with the migration patterns of the eastern Beaufort Sea and eastern Chukchi Sea stocks.

In the Atlantic Arctic, the Frobisher Bay and South Hudson Bay stocks (IWC, 2000) were subsumed into the western Hudson Bay stock based on the results of movement, distribution, and genetic studies. Tagging studies (Yurkowski et al., 2019) and the genetic profiles of hunted animals (De March and Postma, 2003) both showed that Frobisher Bay is the extreme eastern end of the winter migration of belugas that summer in western Hudson Bay.

The 1999 IWC review recognized four stocks of belugas in the western Russian Arctic based on very limited information. These were Franz Josef Land, Ob Gulf, Yenisey Gulf, and Southwest Laptev Sea (IWC, 2000). These designations were based on limited reports of aggregations and the considerable distances between the known aggregation areas. However, the GROM found little new information on the movements and distributions of these belugas, and the available data on mtDNA lineages, occurrence, and distribution did not support separation of these stocks (Meschersky et al., 2018). The workshop concluded that the available data were insufficient to justify more than one stock, and instead it designated a single stock in the Barents-Kara-Laptev Seas.

Similarly, the three formerly recognized stocks in the White Sea—Onezhsky Bay, Mezhenskyi Bay, and Dvinsky Bay (IWC, 2000)—were combined into a single White Sea stock. While the summer aggregations (at least five, in addition to those mentioned above) in the White Sea are well documented, they are not far apart and there are few data to suggest genetic or behavioral separation.

Western Okhotsk Sea Belugas

Belugas in the western Okhotsk Sea were previously thought to consist of two stocks (reproductively isolated units or biological populations): Sakhalin-Amur and Shantar (IWC, 2000). Extensive studies began in this area in 2007. Based on aerial surveys

[7]Lowry, L., R. Reeves, and K. Laidre. 2017. *Delphinapterus leucas*. The IUCN Red List of Threatened Species 2017: e.T6335A50352346 (avail. at http://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T6335A50352346.en). Downloaded on 08 June 2018.

[8]Lowry, L., R. Hobbs, and G. O'Corry-Crowe. 2019. *Delphinapterus leucas* Cook Inlet subpopulation. The IUCN Red List of Threatened Species 2019: e.T61442A50384653 (avail. at http://dx.doi.org/10.2305/IUCN.UK.2019-1.RLTS.T61442A50384653.en). Downloaded on 10 May 2019.

[9]Cervenka, S. 2015. "Update on our beluga whales". Asbury Park Press. Asbury, NJ (avail. at https://www.app.com/story/news/local/land-environment/2015/06/01/beluga-whales-new-jersey/28327751/).

[10]Sea Watch Foundation. 2015. "More rare beluga whales spotted around the U.K. (avail. at https://www.seawatchfoundation.org.uk/more-rare-beluga-whales-spotted-around-the-uk/).

Table 4.—Beluga and narwhal stocks recognized by one or more status reviews: IWC (2000), Laidre et al. (2015), CAFF (CBMP-SAMBR), and this meeting – GROM. Stocks are ordered as they were in the IWC review, stocks from the other reviews that are not the same as one of the stocks in the IWC review are inserted below the most similar IWC stock. The CAFF review only considered stocks within the CAFF area thus some stocks are listed as "outside." The NAMMCO (text footnote 1) review is not included because it considered only the Atlantic Arctic and sub-Arctic and included other seasonal aggregations. Gray shading indicates when the same aggregation of belugas or narwhals was recognized as a stock by all four reviews. Y = recognized as an independent stock, N = not recognized as an independent stock, dd = where review indicated not enough information to delineate a stock. Comments explain differences between the GROM and the other reviews.

Stock/location	IWC, 2000 (no. in IWC report)	Laidre et al., 2015	CAFF (CBMP, SAMBR)	GROM (no. in this report)	Comments from GROM
Beluga					
Cook Inlet	Y (1)	Y	outside	Y (7)	
Bristol Bay	Y (2)	Y	Y	Y (8)	
Eastern Bering Sea	Y (3)	Y	Y	Y (9)	
Eastern Chukchi Sea	Y (4)	Y	Y	Y (10)	
Eastern Beaufort Sea	Y (5)	Y	Y	Y (11)	Called "Beaufort Sea" by IWC, 2000
Eastern High Arctic-Baffin Bay	N	Y	Y	Y (12)	Also called "Somerset Island" and "Canadian High Arctic" stock in previous reviews; includes the West Greenland winter and North Water Polynya winter aggregations used by CAFF
North Water	Y (6)	N	N	N	Included in Eastern High Arctic-Baffin Bay
West Greenland	Y (7)	Y	Y	N	Included in Eastern High Arctic-Baffin Bay; called West Greenland winter by Laidre et al., 2015 and CAFF
Foxe Basin	Y (11)	N	N	N	Included in Eastern High Arctic-Baffin Bay
Southwest Greenland	N	N	Y	Y (19)	Extinct; called "South Greenland- Qaqortoq to Maniitsoq" in NAMMCO, 1999
Cumberland Sound	Y (8)	Y	Y	Y (17)	
Frobisher Bay	Y (9)	N	N	N	Included in Western Hudson Bay
Ungava Bay	Y (10)	Y	Y	Y (16)	Possibly extirpated
Western Hudson Bay	Y (12)	Y	Y	Y (13)	
South Hudson Bay	Y (13)	N	N	N	Included in Western Hudson Bay
James Bay	Y (14)	Y	Y	Y (14)	
Eastern Hudson Bay	Y (15)	Y	Y	Y (15)	
St. Lawrence Estuary	Y (16)	Y	outside	Y (18)	
Svalbard	Y (17)	Y	Y	Y (20)	
Barents-Kara-Laptev Seas	N	N	N	Y (21)	Isolated population with likely several stocks, however GROM decided that there was not enough evidence to separate belugas in this area into any of the putative stocks recognized in past reviews.
Franz Josef Land	Y (18)	N	N	dd	
Kara and Laptev Seas	N	Y	Y	dd	
Ob Gulf	Y (19)	N	N	dd	
Yenisey Gulf	Y (20)	N	N	dd	
SW Laptev Sea-	Y (24)	N	N	dd	
White Sea (WS)	N	Y	Y	Y (22)	Isolated population with likely several stocks, however not enough evidence to separate belugas in this area into any of the 3 putative stocks recognized by IWC (2000)
Onezhsky Bay	Y (21)	N	N	dd	
Mezhenskyi Bay	Y (22)	N	N	dd	
Dvinsky Bay	Y (23)	N	N	dd	
Western Chukchi Sea-Eastern East Siberian Sea	Y (25)	Y	Y	N	Belugas present in fall, winter, and spring, but likely a migration route; belugas are likely from several stocks, mainly Eastern Beaufort, Chukchi, and Bering Sea stocks
Anadyr Gulf	Y (26)	Y	Y	Y (6)	
Okhotsk Sea	N	Y	outside	N	Okhotsk Sea separated into 5 stocks (Shelikhov, Sakhalin-Amur, Ulbansky, Tugursky, and Udskaya)
Shelikhov Bay	Y (27)	N	outside	Y (5)	
Sakhalin-Amur	Y (28)	N	outside	Y (1)	
Shantar	Y (29)	N	outside	N	
Ulbansky Bay	N	N	outside	Y (2)	Previous reviews included this stock in a larger stock called "Shantar"
Tugursky Bay	N	N	outside	Y (3)	Previous reviews included this stock in a larger stock called "Shantar"
Udskaya Bay	N	N	outside	Y (4)	Previous reviews included this stock in a larger stock called "Shantar"
Narwhal					
East Greenland - Barents Sea	Y	N	N	N	Included GROM stocks EGL, NEG, Svalbard–NW Russian Arctic
Svalbard–NW Russian Arctic	dd	N	N	Y (12)	Likely several stocks but not enough data to separate
Svalbard, Franz Josef Land	dd	N	Y	dd	Included in "Svalbard – NW Russian Arctic"
Svalbard	dd	Y	N	dd	Included in "Svalbard – NW Russian Arctic"
North East Greenland (NEG)	dd	N	N	Y (11)	
East Greenland (EGL)	dd	Y	Y	Y (10)	
Baffin Bay Region	Y	N	N	N	Included GROM stocks SI, JS, SS, AI, ES, IB, EBI
Melville Bay (MB)	dd	Y	Y	Y (7)	
Inglefield Bredning (IB)	dd	Y	Y	Y (6)	
Eastern Baffin Island (EBI)	dd	Y	Y	Y (8)	
Jones Sound/Smith Sound	dd	Y	N	N	Separated into two stocks (Smith and Jones)
Jones Sound (JS)	dd	N	Y	Y (2)	
Smith Sound (SS)	dd	N	Y	Y (3)	
Somerset Island (SI)	dd	Y	Y	Y (1)	
West Greenland winter aggregation	dd	Y	Y	N	A winter aggregation of GROM stocks SI, AI, ES, MB, EBI
Admiralty Inlet (AI)	dd	Y	Y	Y (4)	
Eclipse Sound (ES)	dd	Y	Y	Y (5)	
Northern Hudson Bay	Y	Y	Y	Y (9)	

and observations from boats and shore (Solovyev et al., 2015; Solovyev et al.[11]), the population consists of several distinct summer aggregations in 1) Sakhalin Bay–Amur River, 2) Ulbansky Bay, 3) Tugursky Bay, and 4) Udskaya Bay. Nikolaya Bay is also occupied by belugas, but belugas from Sakhalinsky Bay were resighted in Nikolaya Bay in July so they are considered part of the Sakhalin Bay–Amur River aggregation.

Genetic studies demonstrated that belugas summering in the western Okhotsk Sea share a single nuclear gene pool and thus represent a single biological population (Shpak et al., 2019). Analysis of mtDNA markers subdivided belugas summering in different areas into three demographic units: 1) Sakhalin-Amur and Nikolaya Bay, 2) Ulbansky Bay, and 3) Tugursky-Udskaya Bays. Even though Nikolaya and Ulbansky Bays are, in geographical terms, the two arms of Academii Bay, i.e., they share the same entrance from the open sea, a comparison of the haplotype frequencies between Nikolaya and Ulbansky belugas resulted in the highest difference between any pair of bays (F_{ST}=31.1%, p=0.0006). Belugas in Nikolaya Bay also differ from Ulbansky whales in their response to boats, and in this respect they resemble Sakhalinsky Bay belugas (Shpak et al., 2019).

Pairwise comparisons of haplotype frequencies indicate that the maternal lineages of Sakhalinsky, Ulbansky, and Udskaya belugas differ significantly (F_{ST}=11.0–16.1%, p=0.0000). The lack of difference in haplotype frequencies between Tugursky and Udskaya was outweighed by geographical separation (200 km) and behavioral differences to determine that Tugursky Bay belugas and Ulbansky Bay belugas should be managed as separate stocks. For Sakhalinsky, Ulbansky, and Udskaya Bays, intra- and inter-annual resightings suggest sedentary behavior of at least some of the belugas throughout the summer, and fidelity to summer ranges.

There is uncertainty around the differentiation of beluga stocks in the western Okhotsk Sea, but the criteria applied for the structure proposed above (mtDNA frequency differences, observations of spatio-temporal occurrence, and behavior) are similar to those used for stock delineation in other areas. The GROM therefore concluded that, based on information currently available, belugas in the western Okhotsk Sea consist of four stocks: 1) Sakhalin Bay–Amur River, 2) Ulbansky Bay, 3) Tugursky Bay, and 4) Udskaya Bay.

1) Sakhalin-Amur

The Sakhalin-Amur stock occupies the Amur River estuary and Sakhalinsky Bay during the summer months and moves offshore into deeper ice-covered waters of the Okhotsk Sea during the winter (Shpak et al., 2019). This stock is the most extensively studied in the western Okhotsk Sea. Research has included abundance estimation, genetic analyses, satellite tracking, health assessment, and an initial study of contaminant levels. Genetics (mtDNA) and movement data supported this stock designation (Shpak et al., 2019). A small number (30–60) of belugas occupying Nikolaya Bay during the summer are also included in this stock. No differences in the mtDNA haplotype frequencies have been revealed between Sakhalin-Amur belugas and belugas biopsied in Nikolaya Bay (Shpak et al., 2019). An estimate of the average number of belugas available at the surface based on three aerial line-transect surveys (2009 and 2010) is 1,977 (CV=0.24, 1,574–2,293). The surface estimate was multiplied[12] by 2.0 to account for submerged whales (availability bias) in the murky waters of the southern part of Sakhalinsky Bay and the Amur estuary, so that the abundance estimate for this stock is 3,954 (CV=0.24) belugas.

Large-scale commercial beluga hunting in the Okhotsk Sea during the 20th century, primarily before 1960, substantially reduced the population. Starting in the 1980's, live-capture operations have been conducted in the southern part of Sakhalinsky Bay. The captured belugas are sold to aquaria for live displays; they are primarily juveniles 2 or 3 years old, with a sex ratio skewed toward females. Allowed take levels set by the Russian authorities do not consider this narrow age range and sex bias and thus may over-estimate the number of removals that can be sustained. Until 2012, annual live-capture removals were reportedly less than 40. From 2012 to 2015, however, belugas were taken annually in numbers ranging from 40 to over 100 (exact figures are not available). In 2016 there were no live captures, and starting in 2017, the Federal Fisheries Agency recommended that the annual live-capture take in the Sakhalin-Amur area be limited to 40 or fewer individuals.

Major concerns for the Sakhalin-Amur stock include interactions with coastal fisheries (including distur-

[11]Solovyev, B., D. Glazov, V. Chernook, E. Nazarenko, N. Chelintsev, and V. Rozhnov. 2012. Distribution and abundance of beluga whales (*Delphinapterus leucas*) in the White Sea and in the southern part of the Barents Sea based on aerial counts in August 2011. Marine Mammals of Holarctic: Collection of scientific papers of the 7th Intl. Conf., Suzdal, Russia, 24-28 Sept. 2012, vol. 2:264–269 (avail. at http://marmam.ru/upload/conf-documents/mmc2012_full.pdf).

[12]The multiplier 2.0, to account for availability bias (i.e. assuming that half of the belugas remained submerged and were unavailable to be seen and counted by the observer), has been used as a default correction factor for visual aerial surveys of belugas when no availability correction factor has been developed empirically for the stock. This value (2.0) is lower than correction multipliers developed using dive data and aerial survey observer data in some circumstances (e.g., 2.62 belugas in Bristol Bay (Lowry et al., 2008); 2.86, 2.33 and 2.27 belugas during winter in Baffin Bay (Heide-Jørgensen and Acquarone, 2002; Heide-Jørgensen et al., 2010a, 2017)) and higher than those developed in other circumstances (e.g., 1.82 in offshore water with visibility to 4 m deep and 1.15 in shallow nearshore water with visibility to 2 m deep (Innes and Stewart 2002)). This correction multiplier of 2.0 is arbitrary and does not have a CV.

In the Okhotsk Sea, belugas occupy highly turbid waters with visibility typically to less than one meter depth, similar to Bristol Bay. Also, during aerial surveys of the Sakhalin-Amur stock, the plane flew over sea pens with known numbers of belugas, which the observers would count. The counts averaged 44% of the belugas in the pens, which adds support to the notion that at least half of the belugas remained submerged. Unpubl. data, O. V. Shpak, Severtsov Inst. Ecol. Evol. Russian Acad. Sci., 33, Leninsky pr., 119071 Moscow, Russia.

bance, entanglement, and shooting) and contamination of Amur Estuary waters. An additional concern is the potential for competitive interactions with the fishery for chum salmon, *Oncorhynchus keta*, and pink salmon, *O. gorbuscha*. The carrying capacity of the region for belugas has likely declined in recent decades due to the intensive and constantly increasing fishing pressure, especially from the salmon fishery. Entanglement does not appear to be a serious problem despite the large fishing effort, including poaching of sturgeon (kaluga, *Huso dauricus*, and Amur sturgeon, *Acipenser schrenckii*). This comparatively low susceptibility to entanglement (when compared to many other cetaceans) apparently applies to belugas in other areas as well. Salmon fishermen likely shoot belugas at least occasionally. Pollution from the Amur River contains both chemical contaminants (e.g., heavy metals, PCB's; Glazov et al.[13]) and infectious disease agents, especially during flood events (a spike in infections of belugas was observed in 2013; Alekseev et al., 2017).

Workshop Discussion

The trend for this stock is unknown. However, based on a population model using commercial catch data beginning in 1915, recent removals for live display, and an estimate of subsistence removals, it was estimated that there were 13,200 to 20,800 belugas in this stock historically (Bettridge et al., 2016). Current abundance may be at only 20–40% of historical abundance but the model suggests that the current population is increasing.

Status

The workshop judged this stock to be of moderate concern because it is still reasonably abundant and there are no immediate major threats. The primary concerns are the unknown trend in abundance, the likely depletion caused by removals prior to the 1960's, and habitat issues that include the industrial and agricultural pollutants in discharge from the Amur River. Additionally, fisheries are increasing in the area and may be altering the habitat carrying capacity.

2) Ulbansky

The Ulbansky stock occupies Ulbansky Bay during the summer months and moves offshore, presumably into deeper ice-covered waters of the Okhotsk Sea, during the winter as does the Sakhalin-Amur stock (Shpak et al., 2019). This stock is considered a separate demographic unit based on multi-year observations of summer aggregations in the bay as well as genetic evidence (Meschersky et al., 2013; Yazykova et al.[14]). In autumn, some belugas from Sakhalinsky Bay move into Nikolaya Bay, and these belugas may also visit Ulbansky Bay. However, beluga numbers in all bays decrease in autumn. Winter migratory routes and feeding habitats are unknown. Nonetheless, analyses of biopsy samples collected during summer indicate that composition and frequency of the maternal lineages represented in Ulbansky Bay differ from those in the other bays: pairwise comparison of mtDNA yielded F_{ST} values of 16.1% (p=0.0000) for Udskaya Bay, 13.8% (p=0.0000) for Sakhalinsky Bay, and 11.3% (p= 0.0002) for Tugursky Bay. For Nikolaya Bay, which is geographically the closest to Ulbansky Bay, the F_{ST} values are highest, reaching 31.1% (p=0.0006, though this is from a small sample, n=9).

A direct count of 1,167 belugas during an aerial survey in August 2010 was corrected for availability using a correction factor[12] of 2.0 (due to the murky estuarine water), resulting in an abundance estimate of 2.334 whales. The stock is not known to have been commercially exploited nor have live captures occurred in this area. Although predation on belugas by killer whales, *Orcinus orca*, has not been observed directly, on numerous occasions researchers have witnessed a panic escape reaction by the entire aggregation when approached by killer whales. A fishing plant deploys salmon nets along the coast and in the Ulban River mouth, and a gold-mining company (with a mining claim on the Ulban River arm) uses an area on the coast to load and unload machinery and fuel. The main concerns, neither of them major at present, are occasional entanglement, shooting by fishermen, and the risk of habitat contamination by gold-mine discharge.

Workshop Discussion

A beluga satellite-tagged in September 2015 on a shoal in Ulbansky Bay later travelled to Nikolaya Bay, and the researcher suspected it was from the Sakhalin-Amur stock. This illustrates the need for further satellite tracking studies to understand the movements of these stocks after the period of summer residency.

Status

The trend in abundance is unknown, though Russian scientists think that the numbers are stable. The GROM workshop had moderate concern for this stock, primarily because of the unknown trend in abundance and the potential impacts of fishing activities and resource extraction and development in the area.

3) Tugursky

The Tugursky stock occupies Tugursky Bay during the summer months and moves offshore, presumably into deeper ice-covered waters of the Okhotsk Sea, during the winter as does the Sakhalin-Amur stock (Shpak et al., 2019). The identity of this stock as a separate demographic unit within the western Okhotsk population is based

[13]Glazov, D. M., O. V. Shpak, D. P. Samsonov, V. V. Krasnova , A. D. Chernetskiy, D. I. Litovka, R. A. Belikov, A. I. Kochetkov, E. M. Pasynkova, V. M. Belkovich, and V. V. Rozhnov. 2014. Persistent organic pollutants in tissues of marine mammals from the Russian Sub-Arctic. Marine Mammals of Holarctic. Abstract Book of the VIII Int. conf. (St. Petersburg, Russia, 22–27 Sept. 2014), p. 93 (avail. at http://marmam.ru/upload/conf-documents/mmc2014_full.pdf).

[14]Yazykova, M. G., I. G. Meschersky, O. V. Shpak, D. M. Glazov, D. I. Litovka, E. A. Borisova, and V. V. Rozhnov. 2012. Molecular genetic analysis of Sakhalin-Amur and Shantar beluga (*Delphinapterus leucas*) summer aggregation in the Sea of Okhotsk. Collection of scientific papers of the 7th Conf. Marine Mammals of Holarctic, Suzdal, Russia, 24-28 Sept. 2012, 2:400–406. (Avail. at http://marmam.ru/upload conf-documents/mmc2012_full.pdf).

on information provided by local residents and on multi-year observations of geographical isolation from all the other beluga summer aggregations in the Okhotsk Sea. Genetic analysis (see below) also supports this separation from the other stocks, except Udskaya Bay (Shpak et al., 2019).

In summer, belugas are regularly seen in the upper part of the bay and occasionally along the west coast, but are not observed between Tugursky and Udskaya bays. Small groups have been reported near the south coast of Big Shantar Island and along the northeast coast of Tugursky Bay. Behavioral differences (e.g., response to boats) were noted between beluga groups in Tugursky and Udskaya bays. Winter migratory routes and feeding habitats are unknown. Genetic analyses of samples collected during summer indicate that the composition and frequency of the maternal lineages represented in Tugursky Bay differ from those in Sakhalinsky (F_{ST} =8.2%, p=0.0001) and Ulbansky (F_{ST} = 11.3%, p=0.0002) bays. However, no difference was found between Tugursky and Udskaya in a comparison of 32 and 90 specimens, respectively (F_{ST}=1.4%, p=0.1263; Shpak et al., 2019).

Historical data, together with multi-year shore, boat, and aerial observations, indicate that in summer belugas occupy estuarine areas in both bays, separated by around 200 km, and few animals are detected outside the estuaries, which suggests that there is little interchange during summer. Furthermore, behavioral differences between belugas concentrating in Tugursky and Udskaya Bays were noticed by two independent research teams. Until tracking studies of individuals show movement between the two bays in summer, Tugursky Bay belugas should be managed as a separate stock.

An abundance estimate of 1,506 whales was derived from a direct count during an aerial survey of Tugursky Bay in August 2010, multiplied[12] by 2.0 to account for availability bias, i.e., animals missed because they were submerged in murky waters (Shpak et al., 2019). The stock was exploited both for subsistence and commercially from the late 1800's and until the 1950's. Belugas are still taken occasionally by locals, either as a result of bycatch in salmon nets followed by a kill or by shooting. No live-captures have been made from this stock. There is a settlement, a fish plant, and a coastal gold-mining company based in the bay. The main concerns for Tugursky belugas are 1) fisheries, 2) potential habitat contamination caused by gold ore mining (heap leaching), and 3) discharges of human and livestock waste.

Workshop Discussion

No genetic evidence of differentiation between Tugursky and Udskaya belugas is currently available, but what is known about summer distribution and differences in behavior supports the idea of managing the whales that summer in the two bays separately. Genetic studies could be continued to clarify the stock identity of belugas summering in Tugursky Bay, however, given the lack of differentiation, satellite tracking studies showing summer movements of the Tugursky Bay and Udskaya Bay stocks may be the only way to resolve the issue.

Status

Abundance of Tugursky belugas is thought by Russian scientists to be fairly stable, but the actual trend is unknown. The GROM had moderate concern for this stock, primarily due to the uncertainty surrounding stock identity and trends in abundance as well as the issues related to fishing and pollution.

4) Udskaya

The Udskaya stock occupies Udskaya Bay during the summer months and moves offshore, presumably into deeper ice-covered waters of the Okhotsk Sea, during winter as does the Sakhalin-Amur stock (Shpak et al., 2019). The identity of this stock as a separate demographic unit within the western Okhotsk population is based on local knowledge, multi-year observations of summer and autumn aggregations in the bay, and genetic analysis (Shpak et al., 2019). Belugas are present in the estuary of the Uda River from June to October and often enter the Uda River itself. They are also known to concentrate in the estuary of the Torom River. No genetic samples from the Torom Estuary are available, but belugas are regularly seen along the coast between the two rivers (ca. 45 km distance between the mouths), which suggests that all animals in the bay belong to the same stock. Upon ice formation in the Uda Estuary, belugas move along the entire south coast of the bay, but keep near the coastline. Winter migratory routes and feeding habitats are unknown.

The composition and frequency of the maternal lineages represented in Udskaya Bay strongly differ from those in Sakhalinsky, Nikolaya, and Ulbansky bays, and pairwise F_{ST} values are 11.0–16.7%, p<0.002 for all pairs (Shpak et al., 2019). However, no difference was found between the Udskaya and Tugursky samples (F_{ST}=1.4%, p=0.1263). A larger genetic sample from Tugursky Bay collected before late August and sampling in the Torom River estuary in Udskaya Bay are required to better understand the summer stock structure of Tugursky and Udskaya belugas. Differences in behavioral responses to the presence of boats have been noted between Tugursky and Udskaya beluga groups (Shpak[15]).

Abundance of the Udskaya stock was estimated to be 2,464 whales; a direct count of 1,232 belugas during aerial surveys in August 2010 was multiplied[12] by 2.0 to correct for availability bias in murky waters (Shpak and Glazov, 2013). The stock was hunted by locals and commercially until the 1950's. At present, belugas are occasionally taken by local residents, either as a result of bycatch in salmon nets followed by a kill, or by shooting, even though all such takes are illegal. No live captures have been attempted from this stock. There are two

[15]Shpak, Olga V., Severtsov Institute of Ecology and Evolution of Russian Academy of Sciences, 33, Leninsky pr., 119071 Moscow, Russia.

settlements, three fishing plants with multiple fishing camps, three coastal gold-mining bases, and one gold ore loading terminal in the bay. Diesel fuel is unloaded in at least four locations. The main concerns for this stock are the potential impacts of fisheries, habitat contamination by toxic river discharge (discharges from gold mining and of human and livestock waste), and ship traffic (noise, leaks of diesel fuel).

Status

The Udskaya stock is a medium-sized stock (i.e., between 2,000 and 5,000 belugas), with an unknown trend in abundance. A moderate concern for this stock arises mainly due to ship traffic, fishery interactions, and pollution in the area.

5) Shelikhov

The Shelikov stock summers in coastal areas of the northeastern Okhotsk Sea—specifically in Shelikhov Bay and along the west coast of the Kamchatka Peninsula. Its winter range is not known but is thought to be in deeper waters offshore from the observed summer range (Shpak et al., 2019). Reproductive isolation of this stock from other belugas in the Okhotsk Sea was confirmed by genetic studies (Shpak et al., 2019). Strong differences in microsatellite loci alleles (F_{ST}=3.17–4.38%, p=0.0000) and mtDNA haplotype frequencies (F_{ST}=34.0–35.3%, p=0.0000) were found for Shelikhov belugas when compared (pairwise) to the Sakhalin-Amur stock and the combined Shantar region sample. Summer aerial surveys also showed discontinuity in the coastal distribution of these whales and that of whales in the western Okhotsk population. In summer, Shelikhov belugas concentrate both in river estuaries and along the coastline. Very limited information exists on the winter distribution of Shelikhov belugas. In the 1980's, belugas were found along the ice edge in Shelikhov Bay, along the Kamchatka Peninsula in January, and in Shelikhov Bay in April. A beluga tagged with a satellite-linked transmitter in Shelikov Bay remained at the mouth of the bay until at least December.

A direct count by an aerial survey in August 2010 found 1,333 belugas. This was multiplied[12] by 2.0 to correct for whales submerged in the murky waters to estimate abundance of the Shelikhov stock at 2,666 belugas (Shpak and Glazov, 2013). The total allowable take (TAT) level for the West Kamchatka fishing subzone (including both hunting removals and live-captures) varied from 0 to 400 belugas during 2006–11 and since 2012 has varied from 0 to 50, averaging 25/yr during 2012–18. No legal beluga harvest or live-capture effort is reported to have taken place, other than temporary captures for tagging followed by release. The annual illegal take by local residents (for human consumption or dog food) is thought to be fewer than 10 whales, if any. The population trend is unknown. The only potential threat is competition with fisheries in a few populated areas.

Workshop Discussion

This stock is isolated geographically and reproductively. The aerial survey covered only a portion of the range, so the abundance estimate (2,666) may be negatively biased. The small numbers of direct removals are likely sustainable. This area is sparsely settled, has little fishing activity, and therefore bycatch is considered negligible. There are no current development projects in the region. Climate change will likely result in a reduction of sea ice, which could open up the area to development.

Status

This stock is medium-sized with no information on trend. The quota (TAT) issued has not been used, but there are a few illegal removals. At present there is little development in the area. There was some concern about the poor knowledge of population structure but overall, the level of concern for this stock was low.

6) Anadyr

The Anadyr beluga stock consists of a single summer aggregation, which congregates in the shallow waters of the Anadyr River Estuary (western Bering Sea) during late summer, moves out into the Gulf of Anadyr and north to Kresta Bay in autumn, then south to shelf areas in the vicinity of Cape Navarin where it spends the winter. The whales return to the Anadyr Estuary the following summer after the ice has broken up (Shpak et al., 2019). This stock is separated genetically and geographically from the Okhotsk Sea belugas. The composition of mitochondrial lineages shows evident differences (seasonal isolation) between the Anadyr belugas and other stocks in the Bering, Chukchi, and Beaufort Seas (B-C-B stocks) (Meschersky et al., 2013; Borisova et al.[16]). Thus, this aggregation should be managed as a separate stock. To some extent, Anadyr belugas are also reproductively isolated from other B-C-B stocks (Shpak et al., 2019), although more studies are required to understand the degree of this isolation.

In the Anadyr Estuary, some of the same individuals (based on unique markings such as scars) have been resighted within and between years (Prasolova et al., 2014; Prasolova et al.[17]). Together with the results of genetic analysis, observations suggest that in summer, belugas form a residential aggregation in the estuary and return to the same area summer after summer.

[16]Borisova, E. A., I. G. Meschersky, O. V. Shpak, D. M. Glazov, D. I. Litovka and V. V. Rozhnov. 2012. Evaluation of effect of geographical isolation on level of genetic distinctness in beluga whale (*Delphinapterus leucas*) populations in Russian Far East. Collection of scientific papers presented at the 7th Int. Conf., Marine Mammals of the Holarctic, Suzdal, 2012, 1:107–111 (avail. at http://marmam.ru/upload/conf-documents/mmc2012_full.pdf).

[17]Prasolova, E. A., D. I. Litovka, and R. A. Belikov. 2018. The results of photo identifiation of beluga whales (*Delphinapterus leucas*) in the Anadyr Estuary of the Bering Sea in 2013–2015. Collection of scientific papers presented at the 9th Int. Conf., Marine Mammals of the Holarctic: Astrakhan, 2016, 2:109–115 (avail. at http://marmam.ru/upload/conf-documents/mmc2016_full.pdf).

Belugas spend the ice-free summer–autumn feeding period in the Anadyr Estuary (total of 5–6 months, with the latest sighting in late November). During this period, they concentrate in the river deltas but visit all reachable parts of the estuary and occasionally go as far as 300 km upstream in the Anadyr River (Litovka, 2002). According to satellite tracking data, the whales begin to leave the area with the beginning of ice formation in the estuary. First, they move north along the coast to Kresta Bay, and later to the middle and southern parts of Anadyr Gulf (Litovka et al., 2013; Shpak et al., 2019). Anadyr belugas spend the winter around Cape Navarin, in regions with ice coverage of up to 80–90% (Shpak et al., 2019; Litovka[18]).

Results of telemetry and aerial surveys suggest that, in the winter–spring feeding areas off Cape Navarin, Anadyr belugas overlap with some of the B-C-B stocks, most likely the eastern Beaufort Sea stock in particular (Citta et al., 2017). Genetic pairwise comparisons between the Anadyr stock and the others in the Bering Sea and the stocks in the Sea of Okhotsk show it to be differentiable from the other stocks but most similar to the eastern Beaufort Sea stock (Meschersky et al., 2013).

No summer aerial counts of belugas have been conducted in Anadyr Gulf. Litovka (2002) suggested that this summer stock numbers some 3,000 animals based on several years of observations of the numbers of belugas passing the city of Anadyr and entering the Anadyr River during the late spring.

The TAT for the Anadyr Estuary and Anadyr Gulf is 40 belugas. The known subsistence harvest is generally around 2 belugas per year (average of 1.8 from 1997 to 2016), and no live-capture operations have been conducted in this region since 2007. Incidental mortality is typically only 1–3 belugas per year (Litovka[19]). The population trend is unknown. Habitat and other concerns include potential competition with fisheries, increasing ship traffic, and reduced winter ice cover as a result of climate warming.

Workshop Discussion

The number of belugas in this stock is uncertain; the stock is believed to be stable based on the observations mentioned above, but this is not confirmed by survey or count data. Although the level of exploitation of the Anadyr stock is low (fewer than 10 animals removed per year), a more rigorous baseline of population data is needed, given concerns regarding the potential for oil spills and the anticipated increase in ship traffic in the Bering Strait region.

Status

The Anadyr stock is of moderate size and the level of exploitation is low. Moderate concern for this stock was based on the lack of more rigorous abundance data and the potential impacts of increasing ship traffic, urban expansion, and associated noise and pollution.

7) Cook Inlet

Cook Inlet belugas aggregate near river mouths in upper Cook Inlet, Alaska, during ice-free months (Rugh et al., 2000, 2010). In the fall–winter–spring months, the whales in this stock range more widely throughout the upper inlet (Hobbs et al., 2005; Lammers et al., 2013; Shelden et al., 2015; Castellote et al., 2016). Belugas are rarely seen in the Gulf of Alaska outside Cook Inlet with the exception of a small group that resides year-round in Yakutat Bay (Laidre et al., 2000; O'Corry-Crowe et al., 2015). The Alaska Peninsula geographically isolates this stock from the nearest beluga stock in Bristol Bay (Laidre et al., 2000; Hobbs et al., 2005; Shelden et al., 2015) and mitochondrial DNA analysis shows it to be distinct from other stocks in Alaska (O'Corry-Crowe et al., 2002).

The origin of the small group in Yakutat Bay has been studied using genetic samples collected by remote biopsy and was found to be distinct from but most closely related to the larger population residing in Cook Inlet (O'Corry-Crowe et al., 2015). However, a comparison of mtDNA and microsatellites indicates that the Yakutat Bay group is not likely to be a recent extension of that population, and its origin remains obscure.

The Cook Inlet stock was surveyed each year from 1993 to 2012 (Rugh et al., 2000, 2005; Hobbs et al., 2015a) and in even years thereafter (Hobbs, 2013; Shelden et al.[20,21]). Abundance, estimated to be 328 whales (CV=0.08) in 2016 (Shelden et al.[21]), was updated to 279 (CV=0.06) from a survey in June 2018 (Shelden and Wade[22])

Subsistence hunting of these whales was unregulated prior to 1999, with removals (landed catch plus estimated struck-but-lost) averaging over 60 belugas/yr during 1994–98. This resulted in a significant decline (47%) between 1994 and 1998 from around 653 to 347 whales (Hobbs et al., 2000; Mahoney and Shelden, 2000). The decline raised concern that the stock was depleted (Hobbs et al., 2000) and the Cook Inlet hunters voluntarily refrained from hunting in 1999. In 1999 and again in 2000 the U.S. Government established a moratorium on Cook Inlet beluga whale harvest-

[18]Litovka, D. I. 2013. Ecology of Anadyr stock of the beluga whale *Delphinapterus leucas* (Pallas, 1778). Ph.D. thesis, Voronezh State Univ., Russia, 149 p. [in Russian].

[19]Dennis Litovka is currently with the Office of Governor and Government of the Chukotka Autonomous Region, Str. Bering 20, Anadyr, Russia 689000.

[20]Shelden, K. E. W., C. L. Sims, L. Vate Brattström, K. T. Goetz, and R. C. Hobbs. 2015. Aerial surveys of beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2014. AFSC Processed Rep. 2015-03, 55 p. (avail. at http://www.afsc.noaa.gov/Publications/ProcRpt/PR2015-03.pdf Accessed June 2016).

[21]Shelden, K. E. W., R. C. Hobbs, C. L. Sims, L. Vate Brattström, J. A. Mocklin, C. Boyd, and B. A. Mahoney. 2017. Aerial surveys of beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2016. AFSC Processed Rep. 2017-09, 62 p. (avail. at http://www.afsc.noaa.gov/Publications/ProcRpt/PR2017-09.pdf).

[22]Shelden, K. E. W., and P. R. Wade (Editors). 2019. Aerial surveys, distribution, abundance, and trend of belugas (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2018. AFSC Processed Rep. 2019-09, 93 p. (avail. at: https://repository.library.noaa.gov/view/noaa/22918).

ing except for subsistence hunts conducted under a cooperative agreement between NOAA's National Marine Fisheries Service (NMFS) and Alaska Native organizations. Comanagement harvest plans were not agreed for 1999 and 2000. The plan covering the years 2001 to 2005 allowed takes of one or two whales per year, and no hunt has been allowed since 2005 (NMFS[23]). Nevertheless, the population has declined since 1999, with the most recent ten year trend (2008-2018) being -2.3%/yr (Shelden and Wade[22]). After the unsustainable subsistence hunt was controlled, the stock should have begun to increase; the continued failure to increase suggests that other factors are preventing stock recovery.

In May 2000 the Cook Inlet beluga stock was designated as "depleted" under the U.S. Marine Mammal Protection Act (MMPA), i.e., its abundance was below the maximum net productivity level (MNPL) and thus outside the optimal sustainable population (OSP) range. With no evidence that recovery was occurring, NMFS listed the Cook Inlet beluga as an "endangered" distinct population segment under the U.S. Endangered Species Act (ESA) in October 2008, after which it was listed as "strategic" under the MMPA. NMFS published a Recovery Plan for Cook Inlet belugas in December 2016 (NMFS[23]). Cook Inlet belugas have been listed as "Critically Endangered" on the IUCN Red List since 2006 (Lowry et al.[8]).

Habitat concerns include ship traffic, competition with fisheries, anthropogenic noise (including ship noise), urban and industrial development, chemical and biological pollution, and the cumulative effects of multiple stressors. Effects of climate change such as the loss of winter ice cover, changes in the distribution and abundance of prey, and exposure to parasites and diseases new to the region are also of concern.

A substantial decrease in the use of summer habitat has occurred in the last 40 years; whales were found throughout the upper inlet during summer surveys in the 1970's, but by the mid-1990's they limited themselves to river mouths at the north end of the inlet, Knik and Turnagain arms, and coastal shallows connecting these areas (Rugh et al., 2010; Shelden et al., 2015). It is unknown whether the open-water areas of the inlet became less suitable or a smaller population was concentrating in the best habitat. A significant relationship between salmon escapement and annual number of beluga newborns observed (Norman et al., 2019), when considered alongside a shift in diet from saltwater to freshwater species as determined by stable isotope analysis (Nelson et al., 2018), suggests that competition with salmon fisheries has limited the quality of prey available to belugas and this could explain the continued decline.

This stock is subjected to a great deal of disturbance from human activities (shipping, aircraft noise, oil and gas development, commercial and sport fishing, etc.), much of which occurs within the areas designated as "critical habitat" (Goetz et al., 2007, 2012; Small et al., 2017; Castellote et al.[24]). Hundreds of flights each day land and take off over critical habitat, and the shipping lane in and out of the Port of Anchorage passes through the critical habitat. Waste from the city of Anchorage (ca 300,000 people) undergoes only "primary treatment" (removal of solids) before discharge into Cook Inlet, and runoff, including substantial amounts of de-icing fluids from the Anchorage airport, flows directly into the inlet (Norman et al., 2015). While the large tidal flux may substantially dilute the sewage and runoff, these contaminants flow year round or through entire seasons so they are replaced each tidal cycle by subsequent outfall (Norman et al., 2015).

Smaller offshoots such as Knik Arm and Turnagain Arm, which are parts of the designated critical habitat for belugas, have lower flushing rates than the main inlet and may accumulate contaminants in their sediments (Moore et al., 2000; Hobbs et al., 2015b; Norman et al., 2015). There have been no studies of sediment composition and deposition processes in Cook Inlet. Tissue studies in the 1990's showed that the belugas of Cook Inlet had low levels of contaminants in their tissues compared to belugas in other parts of Alaska (with the exception of elevated copper levels in the kidneys), but there have been no more recent studies (Norman et al., 2015). A gas leak that began in December 2016 could not be repaired until the inlet was ice-free in 2017 (DeMarban[25]), and this provides a cautionary example of the risks of oil and gas development in a seasonally ice-covered area.

Natural hazards include live strandings and killer whale predation. There is an unusually high number of live strandings in Cook Inlet as a result of the large tidal heights (ca 9.2 m: Vos and Shelden, 2005). These hazards may interact. For example, a stranding of killer whales occurred at the same time as a mass stranding of belugas a few kilometers away, and it was suspected that the belugas had stranded while avoiding the killer whales. Predation by killer whales may be a significant source of mortality for Cook Inlet belugas (Vos and Shelden, 2005; Burek-Huntington et al., 2015) and therefore increase the risk of population decline and extinction (Hobbs et al., 2015b).

Workshop Discussion

Harvest regulations published in October 2008 indicated that a limited subsistence hunt by Alaska Natives

[23]NMFS. 2016. Recovery plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). NMFS, Alaska Reg., Prot. Resour. Div., Juneau, AK.

[24]Castellote, M., B. Thayre, M. Mahoney, J. Mondragon, C. Schmale, and R. J. Small. 2016. Anthropogenic noise in Cook Inlet beluga habitat: sources, acoustic characteristics, and frequency of occurrence. Final Wildl. Res. Rep. ADF&G/DWC/WRR-2016-4. Alaska Dep. Fish Game, Juneau, AK.

[25]DeMarban, A. 2017. Divers halt leak in Cook Inlet gas pipeline. Alaska Dispatch News. Retrieved on 5 Oct. 2017 (avail. at https://www.adn.com/business-economy/energy/2017/04/14/divers-for-hilcorp-stop-months-long-cook-inlet-gas-leak/).

could resume only after the population has recovered to at least 350 animals (if other criteria are met, including a high probability of recovering to 780 whales by 2099) (NOAA, 2008). Some GROM participants considered 350 too low a threshold. This number (350) was originally set in 2004 in view of the expressed desire on the part of local people to continue beluga hunting and product use as soon as possible given its cultural significance, and it was believed at the time that if the population averaged over 350 for the previous 5 years and had an increasing trend over the previous 10 years, it could sustain a small harvest. As noted above, the population is now designated as "endangered" and therefore before any harvest is allowed, the management plan must be revised to meet whatever criteria apply under the ESA.

Status

This very small population continues to show no evidence that it is recovering. It is subjected to many anthropogenic stressors, and the cumulative impact of these stressors may explain the lack of recovery. The workshop expressed a high level of concern for this stock.

8) Bristol Bay

Belugas of the Bristol Bay stock are typically found in Nushagak and Kvichak bays and major rivers in the east end of Bristol Bay during summer (Frost et al., 1985; Lowry et al., 2008; Citta et al., 2016) and throughout the northern and eastern parts of Bristol Bay in winter (Citta et al., 2016). Satellite telemetry studies indicate that they remain in the greater Bristol Bay region throughout the year (Citta et al., 2016, 2017).

MtDNA analyses show that Bristol Bay belugas are distinct from other stocks that summer or winter in the Bering Sea. Satellite tagging and a comparison of mtDNA from whales in Nushagak and Kvichak bays found no indication of population substructure within Bristol Bay (O'Corry-Crowe et al., 1997, 2002; Citta et al., 2018).

Aerial surveys were conducted periodically between 1993 and 2016, and the estimate of abundance for Bristol Bay belugas in 2016 was 2,040 (CV =0.22, 95% CI=1,541–2,702, N_{min} = 1,809; Lowry et al., 2008; 2019). The trend in abundance estimated from the uncorrected aerial survey counts was +4.8% per year over the 12-yr period from 1993 to 2005. The 2016 survey produced an estimate similar to that in 2005, suggesting that the population has been stable in recent years.

Abundance in 2011 estimated from genetic mark-recapture analysis using skin biopsies collected annually over the period 2002–11 was 1,928 belugas (95% CI = 1,611–2,337: Citta et al., 2018). This provides support for the accuracy of the aerial survey abundance estimate but is based on older data than the most recent aerial survey estimate.

Data on Alaska Native subsistence harvests within Bristol Bay since 1987 indicate that over the period 2007–16, the annual landed harvest averaged 23 belugas (95% CL = 21–25; Frost and Suydam, 2010; Lowry et al., 2019). Fishery bycatch is not well documented. A PBR of 43 belugas (1,809 × 0.024 × 1.0) was calculated for this population, nearly twice the current annual reported subsistence harvest, which however does not account for struck-but-lost whales. Habitat concerns include loss of sea ice due to climate warming, fishery bycatch, oil and gas development, and mining.

Workshop Discussion

The trend for this stock appears to be stable (and it may be increasing). Removals by hunting and bycatch appear to be sustainable, and there are no major habitat concerns. There is a large salmon fishery in Bristol Bay, and while there is little reported bycatch or conflict, competition between the belugas and the fishery may occur since the fishery occurs in areas where belugas feed on the same species. This area has only small human communities, but there are plans for more development (e.g., a major mining project, the Pebble Mine, has been proposed in the watershed of Bristol Bay).

Status

The Bristol Bay stock is a medium-sized stock and is one of the most data-rich, with a time series of credible abundance and trend estimates and reliable data on landed catch. Therefore, concern for this stock is low.

9) Eastern Bering Sea

Eastern Bering Sea belugas aggregate near the mouth of the Yukon River and in Norton Sound in western Alaska throughout the summer (Lowry et al., 2019). As ice forms during the autumn they move offshore to wintering areas south and west of the Kuskokwim River Delta and east of Saint Matthew Island, and continuing south in the eastern Bering Sea as far south as Round Island in Bristol Bay (Citta et al., 2017). Analyses of mtDNA found these belugas to be genetically distinct from adjacent stocks (O'Corry-Crowe et al., 1997, 2002; Brown Gladden et al., 1997; Meschersky et al., 2008).

An aerial survey flown across Norton Sound and adjacent to the Yukon River Delta in 2000 resulted in a population estimate of 6,994 (CI= 3,162–15,472) whales (Lowry et al., 2017b). No previous survey results are available for assessing trend.

The hunting of eastern Bering Sea belugas is comanaged by the Alaska Beluga Whale Committee and NMFS. Belugas from this stock are an important subsistence resource for at least 21 villages in western Alaska. From 2007 to 2016, an average of 190 belugas were landed (i.e., not including struck-but-lost) per year (Frost and Suydam, 2010; Lowry et al., 2019). There are several commercial fisheries in State of Alaska and Federal waters that have the potential to catch belugas incidentally but no such catches have been reported. At least one beluga is known to have been taken in a subsistence fishing net, so bycatch occurs at least occasionally.

Based on the population estimate from 2000, PBR is calculated from: N_{BEST} = 6,994; CV = 0.37; N_{MIN} =

5,173, R_{MAX} = 0.048; F_R = 1.0; PBR = 103. The PBR for this stock is considerably lower than the cumulative reported landings in subsistence hunts (Lowry et al., 2019). Despite this, the harvest has been judged by U.S. authorities to be sustainable because the 2000 survey estimate is thought to be biased low and because local and traditional knowledge indicates that there has not been any decrease in abundance. Nonetheless, an updated population estimate is needed. There are concerns about how this stock may be affected by habitat changes, loss of winter sea ice, and increases in commercial shipping and commercial fishing as a result of climate change.

Workshop Discussion

The single abundance estimate for this stock is believed to be negatively biased due to 1) the use of an availability bias correction (2.0) that was considered low (c.f. 2.62 x 1.18 used for similar high-turbidity water conditions in Bristol Bay; Lowry et al., 2008, 2019), 2) the fact that survey coverage did not include some offshore and in-river areas where belugas are known to occur, and 3) the fact that some of the survey effort took place in sea states greater than Beaufort 3, which likely decreased the sighting rate. A new abundance survey occurred in 2017, but the results were not available to the GROM workshop.

The reported landed catch is nearly twice the PBR value calculated using the results of the 2000 survey, which is now 18 years old; struck-but-lost belugas are not accounted for in the harvest numbers and while 21 communities report takes, other communities that may hunt belugas do not report. Thus total removals are certainly higher than the reported landings.

Concern was expressed over the lack of a more recent abundance estimate and the fact that the relatively high level of removals, possibly twice the PBR, could be causing a decline. However, since the stock is not designated as "depleted" under the MMPA, its current abundance is implicitly assumed to be within the OSP range, i.e., larger than MNPL, for this population, and therefore hunting by Alaska Natives for subsistence is unregulated.

Status

This is a moderate-sized stock of over 5,000 belugas. However, the abundance estimate is from data that are 18 years old, and no information is available on trend. Given that the reported removal levels are likely biased low and the abundance estimate is outdated, but that plans are underway to update the abundance estimate, this stock is of moderate concern. A new estimate expected from a 2017 survey will inform a reassessment of the stock.

Update

In June 2017 NMFS conducted an aerial survey of this stock. The survey analysis estimated surface numbers of 4,621 belugas (CV=0.12); applying the availability bias multiplier[12] of 2.0 yields an abundance estimate of 9,242 belugas (CV=0.12; Lowry et al., 2019). As above, this arbitrary correction factor for missed animals of 2.0 has no associated CV. PBR is calculated from: N_{BEST} = 9,242; CV = 0.12; N_{MIN} = 8,357, R_{MAX} = 0.048; F_R = 1.0; PBR = 201. The 10-year average annual subsistence landed take of 191 is below this new PBR, but with struck-but-lost added, average annual removals are 215, or 7% above PBR and under-reporting is not included (Lowry et al., 2019).

10) Eastern Chukchi Sea

Eastern Chukchi Sea belugas aggregate along Kasegaluk Lagoon in northwestern Alaska in late June and early July (Frost et al., 1993). During summer, they occur in the Beaufort Sea and Arctic Ocean and can venture north as far as lat. 81° N, but they mostly use the continental slope. They migrate south into the Bering Sea in autumn and spend the winter between St. Lawrence Island and the Chukotka Peninsula. MtDNA studies found this stock to be genetically distinct from other stocks in the Bering-Chukchi-Beaufort region (O'Corry-Crowe et al., 1997, 2002; Brown Gladden et al., 1997; Meschersky et al., 2008).

Previously it was believed that the belugas in Kotzebue Sound in mid-June migrated north to near Kasegaluk Lagoon and that the whales in these two locations belonged to the same stock (Lowry et al., 2019). Genetic data from tissue samples obtained during the late 1970's and early 1980's showed that the animals from the two areas were actually from different stocks (O'Corry-Crowe et al., 2016). Numbers of belugas in Kotzebue Sound declined markedly in the mid-1980's. The small number of animals sampled for genetics in Kotzebue Sound since the 1990's may have come from the eastern Beaufort Sea stock.

Aerial surveys flown between 19 July and 20 August 2012 estimated the stock size at 20,675 (CV=0.66) animals (Lowry et al., 2017a), including correction for animals outside the survey area and below the surface based on satellite tag data. The previous abundance estimate from 1992 was 3,710, but it was negatively biased as it included only belugas seen near shore. Therefore, no information is available on population trend.

Belugas from this stock are an important subsistence resource for several villages in northern Alaska, especially Point Lay and Wainwright. From 2007 to 2016, an average of 57 belugas was harvested (i.e., landed) annually by these two villages (Frost and Suydam, 2010; Lowry et al., 2019). Some animals are caught in salmon fishing nets, but they are reported as part of the beluga subsistence take, which is considered sustainable. The PBR set using the 2012 population estimate suggests that removal of 249 belugas per year would be sustainable, and this is well above the current level of removals.

Concerns about beluga habitat include possible impacts of climate change, commercial shipping, oil and gas activities, and tourism. Commercial activities, scientific studies on a wide variety of topics, and tourism have increased as sea ice has dimin-

ished due to climate change. Changes in migration timing related to recent delayed sea ice formation and warming of the Arctic have been documented in this stock (Hauser et al., 2017).

Workshop Discussion

The question of whether there is one segment of the population that comes close to shore and is therefore more susceptible to harvest was discussed. While this is possible it is unlikely to be a small portion of the population as satellite telemetry shows that whales tagged near shore spend most of their time offshore (Suydam[26]). A portion of the stock aggregates in nearshore waters over a 2- to 4-week time period presumably to molt. They do not seem to come inshore to feed as belugas harvested near shore rarely have prey in their stomachs (Quakenbush et al., 2015).

Status

There are no previous abundance estimates that would allow assessment of trend, but this relatively large stock is thought to be stable, and the small number of removals is likely sustainable. Therefore, there is a low level of concern for the stock.

11) Eastern Beaufort Sea

Belugas of the eastern Beaufort Sea (EBS) stock summer in the eastern Beaufort Sea and Amundsen Gulf (Norton and Harwood, 1985; Harwood et al., 1996; Richard et al., 2001; Harwood and Kingsley, 2013; Harwood et al., 2014a; Citta et al., 2017) and over-winter in the Bering Sea (Citta et al., 2017). MtDNA analyses of samples from hunted animals identified EBS belugas as distinct from other stocks in Alaska and eastern Russia, and from central and eastern Canadian Arctic stocks, most likely due to maternally directed annual philopatry to the Beaufort Sea region (O'Corry-Crowe et al., 1997, 2002; Brown Gladden et al., 1997). Analyses of nuclear DNA microsatellite loci indicated that there is some interbreeding with other stocks that winter in the Bering Sea (Brown Gladden et al., 1999).

The only large-scale effort to estimate abundance of the EBS stock was an aerial survey conducted in 1992, resulting in a near-surface abundance estimate of 19,629 (CV=0.23; Harwood et al., 1996), which was multiplied[12] by 2.0 to account for submerged whales and whales outside of the survey area to get an estimate of 39,258 (CV=0.23; Allen and Angliss, 2015). The correction factor (2.0) was not based on data and was used without a CV. It was considered to be a reasonable minimum value, and it is supported by the observation of Richard et al. (2001) that 13 of 18 whales satellite-tracked in 1993 and 1995 remained outside of the 1992 survey area, suggesting that the survey covered only about 38% of the stock.

There has been a long history of beluga hunting by the Inuvialuit and their ancestors in the western Canadian Arctic, and by the Iñupiat in Alaska (Harwood et al., 2002). The EBS stock is hunted by the Inuvialuit during summer in the Mackenzie River estuary and by the Iñupiat in Alaska during the spring migration. Based on annual harvest numbers reported by Canada and the United States, the mean estimated annual subsistence take (landed plus struck-but-lost) between 1987 and 2015 was 164 whales (Harwood et al., 2002; Frost and Suydam, 2010; Harwood et al., 2015; Muto et al., 2016), which is well below the PBR of 487 (using a recovery factor of 0.75 because the survey estimate is outdated).

An average of ten belugas per year are taken in fall, winter, and spring in Chukotka, and these animals are generally considered to be from this stock based on genetic data and the timing and location of the takes (Boltunov and Belikov, 2002, updated by D. Litovka[19]). These takes are considered sustainable when added to the Canada and United States takes.

Size-at-age of belugas landed in the Mackenzie Delta has declined from 1989 to 2008 (Harwood et al., 2014b). The subtle changes in growth of belugas over the time-series may reflect ecosystem changes that have reduced the availability or quality and quantity of their prey or that the stock is approaching carrying capacity (Harwood et al., 2014b, 2015).

Workshop Discussion

In a previous assessment by the Department of Fisheries and Oceans Canada (DFO), the estimated total of direct removals by hunting prior to 2000 was 186 belugas per year (DFO[27]), which includes a correction for struck-but-lost; the catch was strongly biased toward males (60–80% of removals). That assessment concluded that the annual harvest was far below a level that might negatively affect such a large population.

Status

This is a very large stock (although the most recent abundance estimate is 25 years old) and the trend is unknown. The level of removals appears low relative to the stock's size and the concern level is low.

12) Eastern High Arctic–Baffin Bay

Belugas in the Eastern High Arctic–Baffin Bay stock consist of aggregations summering in the Canadian High Arctic archipelago and, to a minor extent, in Smith Sound. During summer, the main aggregations occupy estuaries, inlets, and small bays in and around Somerset Island (Smith and Martin, 1994; Richard et al., 1998a, 2001; Heide-Jørgensen et al., 2003b; Koski and Davis[28]). Specific locations include Radstock Bay, Maxwell Bay, and Crocker Bay on Devon Island; Cunningham Inlet, Creswell Bay, and Elwin Bay on Somerset Island; and Coningham Bay on eastern Prince of Wales Island. Telemetry information has shown that the stock is divided in

[26]Suydam, R. S. 2009. Age, growth, reproduction, and movements of beluga whales (*Delphinapterus leucas*) from the eastern Chukchi Sea. Ph.D. dissert., Univ. Wash., Seattle, 152 p.

[27]DFO. 2000. Eastern Beaufort Sea beluga. DFO Science Stock Status Report E5-38. (Avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[28]Koski, W. R., and R. A. Davis. 1980. Studies of the late summer distribution and fall migration of marine mammals in NW Baffin Bay and E Lancaster Sound, 1979. LGL Ltd. for Petro-Canada Explor. Inc.

winter into a portion that resides in the North Water polynya and a larger portion that resides in coastal ice-free areas along the Baffin Bay sea-ice edge off West Greenland (Doidge and Finley, 1994; Richard et al., 1998a, 1998b; Heide-Jørgensen et al., 2003b; Heide-Jørgensen and Laidre, 2004).

Abundance on the summer range was estimated from an aerial survey in 1996 to be 21,213 belugas (95% CI 10,985–32,619; Innes and Stewart, 2002). This is the only total abundance estimate for this stock. Winter surveys of belugas off West Greenland cover only a portion of the stock but indicate an increase in abundance in this wintering area since the imposition of catch limits in Greenland (Heide-Jørgensen et al., 2017). A fairly recent (2012) abundance estimate from these surveys was 9,072 whales (95% CI 4,895–16,815; Heide-Jørgensen et al., 2016).

During summer, approximately 100 belugas per year are removed from this stock by communities in Nunavut, and about 300 belugas are taken per year by communities in Greenland in winter when they are close to shore. Total removals in both areas have declined in recent years (non-quota in Canada and quota harvest in Greenland) (NAMMCO[29]). The decline in catches in winter off Greenland is related to the recent decline of winter sea ice in eastern Baffin Bay which has reduced access to belugas by Greenlandic hunters (Heide-Jørgensen et al., 2010a). In total, the harvest is considered sustainable, and recent declines in removals should allow the stock to increase. However, the stock is still depleted due to past commercial hunting. Numbers prior to the commercial hunting were estimated by a population model to be at least twice the current abundance (Innes and Stewart, 2002).

Habitat concerns include the effects of climate change and increasing industrialization and shipping. Continued ice loss may affect the availability of prey species and reduce the carrying capacity. Impacts will depend on the adaptability of belugas—e.g., their ability to change their summer and winter aggregation sites and migration timing and adjust to alternative prey. There are also habitat concerns related to the Baffinland Mary River Mine project (NAMMCO[29]), which has proposed to use ice breaking in winter and spring to resupply the mine and transport iron ore. The implications of this activity for belugas migrating and wintering in Baffin Bay are unclear at present.

Workshop Discussion

More information is needed about areas that are important for foraging, especially in Baffin Bay, as prey populations may have changed. For example, Atlantic cod, *Gadus morhua,* were important prey of belugas during the "cod invasions" in West Greenland in the 1920's but their importance as prey declined with the disappearance of cod in this region (Degerbøl and Nielsen, 1930). It is unknown if the recent increase in cod abundance in West Greenland has benefited the belugas. Additionally, capelin, *Mallotus villosus,* are increasing in Cumberland Sound and off Labrador (Rose and Rowe, 2015), and this may represent a new food resource for Baffin Bay belugas.

Uncertainty remains regarding the stock affinity of belugas in Foxe Basin; their range may overlap that of Somerset Island belugas at least during summer. While genetic results suggest that these belugas are related to the western Hudson Bay stock (Brown Gladden et al., 1997; De March and Postma, 2003), their distribution is not well known and the southern extent of the Somerset aggregation is poorly defined.

Status

It is not clear whether abundance of the Eastern High Arctic–Baffin Bay stock is stable or increasing—winter surveys off West Greenland indicate an increase in one wintering area since the imposition of catch limits (Heide-Jørgensen et al., 2017). This is a large stock (possibly 20,000 animals) and removals are considered sustainable, so the level of concern for this stock is low.

13) Western Hudson Bay

Western Hudson Bay (WHB) belugas are centered around the Seal, Churchill, and Nelson River estuaries during summer, although belugas occur along the entire west coast of Hudson Bay (Sergeant, 1973; Sergeant and Brodie, 1975; Richard et al., 1990; Richard, 1994). The distribution of WHB belugas overlaps that of the Eastern Hudson Bay (EHB) stock during the spring and fall migrations and in overwintering areas in Hudson Strait (Turgeon et al., 2012). WHB belugas are more diverse genetically than other Canadian beluga stocks, but they are genetically distinct from the neighboring EHB stock (De March and Postma, 2003). The previously recognized (but with reservations) Frobisher Bay and South Hudson Bay stocks (IWC, 2000) are included here in the western Hudson Bay stock based on the results of studies of movements and distribution (Yurkowski et al., 2019) and genetics (De March and Postma, 2003).

WHB beluga abundance was estimated using data from visual and photographic aerial surveys in 1987 (Richard et al., 1990), 2004 (Richard[30]), and 2015 (Matthews et al.[31]). The most recent estimate (adjusted for availability bias) is 54,473 (CV=0.098; CI = 44,988–65,957). Notably, this estimate excludes the coast of Ontario, where ~14,800 be-

[29]NAMMCO. 2017. NAMMCO-JCNB Joint Scientific Working Group on Narwhal and Beluga, 8–11 Mar. 2017, Copenhagen, Denmark (avail. at http://nammco.wpengine.com/wp-content/uploads/2017/06/nammco-jcnb-jwg-report-march-2017-final-with-ex-summ.pdf).

[30]Richard, P. R. 2005. An estimate of the western Hudson Bay beluga population size in 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/017. ii + 29 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[31]Matthews, C. J. D., C. A. Watt, N. C. Asselin, J. B. Dunn, B. G. Young, L. M. Montsion, K. H. Westdal, P. A. Hall, J. R. Orr, S. H. Ferguson, and M. Marcoux. 2017. Estimated abundance of the western Hudson Bay beluga stock from the 2015 visual and photographic aerial survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/061. iv + 18 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

lugas were estimated during the 2004 survey (Richard[30]).

The average of estimated annual removals by communities around Hudson Bay and Hudson Strait from 1977 to 2015 was 503 (range 252–784, including struck-but-lost; Hammill et al., 2017). This removal level is well below the PBR of 1,004 as calculated using the most recent abundance estimate and a recovery factor of 1. The WHB beluga stock is large and the similar near-surface counts during aerial surveys conducted in 2004 and 2015 suggest that the size of this stock is stable.

Workshop Discussion

Ship traffic is a concern. About 2,000–3,000 belugas congregate in the Churchill River estuary where the port of Churchill is located, and shipping that connects communities along the west coast of Hudson Bay occurs throughout the main summer aggregation areas. Icebreaking in Hudson Strait, where the WHB and EHB belugas overwinter, is also a concern for these stocks. Hydroelectric development affecting seasonal river discharge rates into estuaries frequented by belugas in summer is an additional concern.

Status

There is low concern for this stock. This is because it is large and stable, and removals appear sustainable.

14) James Bay

The James Bay (JB) stock apparently occurs in and near James Bay yearround (Bailleul et al., 2012). Twelve animals tagged in the southeastern part of the bay showed no evidence of directional long-distance migration. Genetic analysis confirmed that JB belugas are distinct from the other stocks in Hudson Bay (Postma et al.[32]). However, the differentiation is weak, suggesting recent divergence.

Aerial surveys of James Bay and southern Hudson Bay conducted between 1985 and 2015 found large groups of belugas in northwestern James Bay and along the adjacent Ontario coast of Hudson Bay (Gosselin et al.[33, 34]). The belugas in northwestern James Bay have been included in the James Bay stock, but the stock affinities of these whales and of the whales along the adjacent coast of Hudson Bay have not been confirmed by genetic or movement data. Abundance estimates from aerial surveys of James Bay show large variability between surveys suggesting that there is an influx of animals from western Hudson Bay in some years. The aerial survey in 2015 resulted in an estimate of 10,615 (CV=0.25) which is used as the current estimate for the James Bay stock (Gosselin et al.[34]). No assessment of trends in abundance was attempted.

There was a limited commercial hunt for JB belugas in the 19th century, but this seems to have lasted only a few years, and there was also a limited hunt by some Cree communities (Reeves and Mitchell, 1987b). Since the early 2000's, management plans have encouraged Inuit from Nunavik (eastern Hudson Bay) to harvest belugas in James Bay to reduce the pressure on the endangered EHB stock. However, the hunting by Inuit from Nunavik in James Bay has removed only ~10 whales per year due to the large distance from the nearest community to the whales.

The PBR is set at 173 individuals using a recovery factor of 1. While there is no major concern about this relatively large stock that is exposed to little hunting pressure, knowledge about the stock is limited. Hunters have observed belugas in winter along the southern Belcher Islands, indicating potential northward movement of JB animals during this season. The impacts of changes in the hydrological cycle in the JB habitat caused by hydroelectric development are uncertain.

Workshop Discussion

JB belugas should be considered as a separate stock, although there is some uncertainty regarding the stock's size and seasonal movements. All belugas tagged to date in James Bay have been on the east side and there is no information on the movement patterns of whales on the west side. The habitat in James Bay is changing with a decrease in sea ice, resulting in increased primary productivity. This may be improving habitat quality for belugas.

Status

There is low concern for this stock because it appears to be fairly large despite the uncertainty about which animals are being surveyed in James Bay at times. Additionally, the harvest numbers are low.

15) Eastern Hudson Bay

In summer, the EHB beluga stock occupies an area bounded by the Hudson Bay arc in the east and extending westward to approximately 60 km west of the Belcher Islands. Historically, core summering areas included the Little Whale River and Nastapoka River estuaries, although fewer whales use these areas now likely due to past commercial hunting and overharvesting. Satellite telemetry tracking showed that this stock does not mix with other stocks in Hudson Bay during summer (Lewis et al., 2009), but it moves into Hudson Strait and the Labrador Sea during fall and winter where the animals mix with belugas from the WHB stock (Lewis et al., 2009; Hammill, 2013). Genetic analysis showed that EHB and WHB belugas are from the same breeding population, however, maternally taught migration

[32]Postma, L. D., S. D. Petersen, J. Turgeon, M. O. Hammill, V. Lesage, and T. Doniol-Valcroze. 2012. Beluga whales in James Bay: a separate entity from eastern Hudson Bay belugas? DFO Can. Sci. Advis. Sec. Res. Doc. 2012/074. iii + 23 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[33]Gosselin, J.-F., V. Lesage, and M. O. Hammill. 2009. Abundance indices of beluga in James Bay, eastern Hudson Bay and Ungava Bay in 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/006. iv + 25 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[34]Gosselin, J.-F., M. O. Hammill, and A. Mosnier. 2017. Indices of abundance for beluga (*Delphinapterus leucas*) in James and eastern Hudson Bay in summer 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/067. iv + 25 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

patterns limit mixing of summering aggregations (Turgeon et al., 2012; Colbeck et al., 2013).

The most recent abundance estimate, from a 2015 survey, is 3,819 animals (CV=0.43) (Gosselin et al.[34]). Abundance estimates obtained from seven surveys conducted between 1985 and 2015 suggest that the EHB stock's size has remained stable over that period (Gosselin et al.[34]). Commercial hunting in the 19th century substantially reduced the abundance of this stock (Reeves and Mitchell, 1987b). Even though the intensity of commercial hunting lessened in the 1870's, subsistence hunting continued and probably limited the stock's recovery potential. Harvest limits and seasonal closures were not implemented until the 1980's. The EHB area was closed to hunting from 2001 to 2006. Harvesting resumed in 2007, although the Nastapoka and Little Whale estuaries remained closed.

The beluga sampling program in northern Quebec, which has been operating since 1995, allows samples to be collected from approximately 30% of the belugas landed. Genetic-mixture analysis uses those samples to define the proportions of EHB and WHB belugas taken in the various hunts, both spatially and temporally (Doniol-Valcroze et al.[35]; Mosnier et al.[36]). These proportions are used to determine catch limits for each community and each hunting period. An average of 63 EHB belugas per year were taken (landed catch) during the last 3-year (2014–16) management plan.

A population dynamics model incorporating information on removals, proportions of each stock in the catch, and aerial survey estimates of abundance suggests that the EHB stock declined between 1974 and 2001 and then increased slightly (3,078 to 3,408) until 2016 (Hammill et al., 2017). The recent apparent increase (or stabilization) of the population may have been due to the efforts to focus the harvesting in Hudson Strait where EHB animals constitute a lower proportion of the animals hunted. Harvest limits were set by the Nunavik Marine Region Wildlife Board using an objective of a maximum 50% probability of population decline over a 10-year period, corresponding to a total allowable harvest (landed catch) of 62 animals/yr. These harvest levels accounted for an average 41% struck-but-lost rate (Doniol-Valcroze et al.[35]). The objective for the new management plan has yet to be defined.

Genetic analysis has revealed the summer presence of belugas around the Belcher Islands that may come from one or more stocks other than the EHB stock (Mosnier et al.[36]). However, waters around the Belcher Islands are included in the summering area overflown during the aerial surveys conducted to estimate abundance, and EHB belugas cannot be distinguished from others; thus, there is potential for the size of the EHB stock to be overestimated.

Habitat concerns include icebreaking and shipping and changes in seasonal salinity in estuaries. Icebreaking activities in Hudson Strait during winter and spring to meet the transportation needs of remote mines are a cause for concern. Additionally, hydroelectric dams in the Great Whale and La Grande river drainages may have impacts on belugas as large volumes of fresh water are released into Hudson Bay and James Bay during winter due to the high demand for electricity in that season. The freshwater plumes from these discharges change the nature of the sea-ice in the estuaries and coastal areas, making it much less pliable or friable and more difficult for the whales to gain or maintain access to air, thus increasing the risk of mortality from ice entrapment. The freshwater plume from the Great Whale River may also affect those belugas (if any) from James Bay that overwinter near the Belcher Islands.

Workshop Discussion

The winter harvest of belugas at Sanikiluaq, where recent catch levels appear to be higher than in the past, may include ice-entrapped whales. It is not clear from genetic analyses whether the winter-harvested animals are only from the EHB stock, from another stock, or from a mixture of stocks.

Although the current management regime appears to be maintaining a stable population, there is concern that flexibility for quick response in the event of a population decline is lacking. There is no allowance for errors in allocation of harvested animals to the appropriate stock, and the current management plan fails to incorporate a margin of precaution to ensure population recovery (a central feature of the PBR approach).

Status

There is concern regarding removal levels for the EHB stock; therefore, it is considered to be of high/moderate (1/2) concern (Table 3). While this stock is medium-sized and appears to be stable or increasing slowly, the abundance estimates from surveys may include animals from multiple stocks. If this is true, it would confound conclusions regarding abundance, harvest levels (and division among communities), and the overall sustainability of the harvest. Additional information is needed on the stock identity of belugas and the proportion of each stock (perhaps via a biopsy survey) observed during aerial surveys used for abundance estimation. Besides the harvest, the possible impacts of icebreaking activities in Hudson Strait and of the fluctuations in freshwater flow into the belugas' nearshore habitat in eastern Hudson Bay caused by the hydroelectric project in the Great Whale River drainage are regional concerns.

[35]Doniol-Valcroze, T., J.-F. Gosselin, and M. O. Hammill. 2012. Population modeling and harvest advice under the precautionary approach for eastern Hudson Bay beluga (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/168. iii + 31 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[36]Mosnier, A., M. O. Hammill, S. Turgeon, and L. Postma. 2017. Updated analysis of genetic mixing among beluga stocks in the Nunavik marine region and Belcher Islands area: information for population models and harvest allocation. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/016. v + 15 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

16) Ungava Bay

Sizeable annual estuarine aggregations of belugas occurred in southern and western Ungava Bay until the end of the 19th century, by which time commercial hunting had caused a severe decline in numbers (Boulva, 1981; Finley et al., 1982; Reeves and Mitchell, 1987a). Subsistence hunting continued until the late 20th century when regional hunting closures came into effect. Based on commercial catch data, this stock numbered ~1,900 individuals in the 1800's (DFO[37]), and catches and direct observations in the 1960's and 1970's suggested that only a few hundred belugas remained in the region (Reeves and Mitchell, 1989). A quota system was implemented in 1986, and the Mucalic River estuary was closed to hunting (Lesage et al.[38]).

Five aerial surveys were conducted between 1982 and 2008, and no belugas were seen on-transect in the surveys after 1985 (Smith and Hammill, 1986; Hammill et al., 2004; Gosselin et al.[34]). Off-transect observations in 1993 suggested that there were fewer than 200 individuals in the region (Kingsley, 2000). In 2012, a mean estimate of abundance based on the last four surveys was 32 belugas (95% CI 0-94) (Doniol-Valcroze and Hammill[39]).

No trend can be estimated from currently available data. There are still occasional sightings in the area of the Mucalic Estuary and the Whale River; however, there is no information on the frequency of use of these areas by belugas, and no recent estimate of abundance or genetic information is available.

Workshop Discussion

This stock may be extirpated. Occasional sightings of belugas during the summer in Ungava Bay and nearby parts of Hudson Strait raise questions about whether they are sightings of animals from the Ungava Bay stock. No genetic material from the whales that historically congregated in the Ungava Bay estuaries is available for comparisons with neighboring stocks or recent samples from belugas in Ungava Bay. Consequently, it is not possible to determine if the few whales occasionally seen in Ungava Bay are from the original Ungava Bay stock or how much the stock differed from surrounding stocks. DNA might be extracted from old tissue or bone samples; it is not clear how thoroughly this possibility has been explored.

Status

There is high concern about this stock because it is either extremely small or extirpated.

17) Cumberland Sound

Cumberland Sound (CS) belugas are thought to remain in Cumberland Sound throughout the year with a substantial aggregation occupying Clearwater Fiord during summer months (Richard and Stewart[40]). Aerial surveys of the stock's summer range have found 50–60% of the total abundance to be in the northern portion of the sound outside of Clearwater Fiord (Richard[41]; Marcoux et al.[42]).

Genetic and contaminant analyses show CS belugas to be distinct from other Canadian stocks, including animals harvested by other south-eastern Baffin Island communities (Brown Gladden et al., 1997; De March et al., 2002; De March et al., 2004; Turgeon et al., 2012). However, local traditional knowledge identifies more than one type of beluga in Cumberland Sound with differences noted in body size and shape, coloration, and the taste of the skin (mattaq) (Kilabuk[43]).

Nine aerial surveys of the CS beluga stock's range were conducted between 1980 and 2014 (Richard and Orr, 1986; Richard, 1991b; Richard and Stewart[40]; Richard[41]; Marcoux et al.[42]), and the most recent abundance estimate was 1,151 (CV=0.21). Direct comparisons among all of the surveys to assess trends are not possible because the earlier surveys covered only Clearwater Fiord and would have missed belugas in other parts of the Sound; the most recent four surveys (1990, 1999, 2009, 2014) covered the entire summer range and are comparable.

Hunters from Pangnirtung landed 41 belugas per year, on average, during 2006–15. Struck-but-lost is estimated as 18% of landings, so removals averaged 47 belugas per year. The stock was depleted by commercial hunting in the 1800's and early 1900's (Mitchell and Reeves, 1981).

A population model fit to the survey data (1990–2014) and the reported harvest data (1960–2015, landings only) indicated a declining population with a current abundance of ~1,000 animals (Marcoux and Hammill[44]) Using the modeled CS beluga abundance and a recovery factor of 0.5, which DFO has used as a standard in the past to calculate PBR levels for

[37]DFO. 2005. Proceedings of the meeting on recovery potential assessment of Cumberland Sound, Ungava Bay, Eastern Hudson Bay and St. Lawrence beluga populations (*Delphinapterus leucas*); April 5-7, 2005. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2005/011.224 (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[38]Lesage, V., D. W. Doidge, and R. Fibich. 2001. Harvest statistics for beluga whales in Nunavik, 1974-2000. Fish. Oceans, Sci. Can. Sci. Advis. Sec., Res. Doc. 2001/022. 35 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[39]Doniol-Valcroze, T., and M. O. Hammill. 2012. Information on abundance and harvest of Ungava Bay beluga. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/126. iv + 12 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[40]Richard, P. R., and D. B. Stewart. 2008. Information relevant to the identification of critical habitat for Cumberland Sound belugas (*Delphinapterus leucas*). DFO Can. Sci. Advis. Secr. Res. Doc. 2008/085. iv + 24 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[41]Richard, P. R. 2013. Size and trend of the Cumberland Sound beluga whale population, 1990 to 2009. DFO Can. Sci. Advis. Secr. Res. Doc. 2012/159. iii + 28 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[42]Marcoux, M., B. G. Young, N. C. Asselin, C. A. Watt, J. B. Dunn, and S. H. Ferguson. 2016. Estimate of Cumberland Sound beluga (*Delphinapterus leucas*) population size from the 2014 visual and photographic aerial survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/037. iv + 19 p. (Erratum: October 2016) (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[43]Kilabuk, P. 1998. A study of Inuit knowledge of the southeast Baffin beluga. Nunavut Wildl. Manage. Board, 74 p.

[44]Marcoux, M., and M. O. Hammill. 2016. Model estimate of Cumberland Sound beluga (*Delphinapterus leucas*) population size and total allowable removals. DFO Can. Sci. Advis. Sec. Res. Doc. 2016 (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

populations assessed by COSEWIC as "threatened," the PBR for this stock was set at seven whales (Marcoux and Hammill[44]).

Workshop Discussion

Previously this stock was considered migratory, but belugas seem to remain in Cumberland Sound throughout the year and therefore it is now considered to be resident (and non-migratory). A population model using aerial survey results and available information on removals (Marcoux and Hammill[44]) indicates a 30% chance of future decline in abundance even with no harvest. It is uncertain how well this model and data represent the state of the population, so the model results were not considered reliable to inform management. Local people acknowledge that there has been a decline in beluga numbers; they believe that this was mostly due to historical commercial hunting. Interestingly, blubber cortisol levels, an indicator of chronic stress, are higher for CS belugas than for other stocks, but it is not clear why (Trana[45]).

Status

The CS stock is small in both number and range. It is believed to be declining, and recent harvest levels are considered unsustainable. For these reasons, the concern level is high for this stock.

18) St. Lawrence Estuary

The current distribution of the St. Lawrence Estuary (SLE) beluga stock represents a fraction of its historical range (Mosnier et al.[46]). This population can be differentiated using both nuclear and mtDNA markers (Brown Gladden et al., 1997, 1999; De March and Postma, 2003). Significant ongoing immigration is considered unlikely.

An age-structured population model was used to estimate the 2012 population size at 889 (Mosnier et al., 2015). The model incorporates abundance estimates and the proportion of under-2 year olds from eight aerial photographic surveys between 1988 and 2009 and data on numbers of known deaths by age class as documented through carcass monitoring.

The SLE beluga population was severely depleted by a sustained hunt from the late 1800's to the mid-1900's, and hunting was finally prohibited in 1979 (Reeves and Mitchell, 1984). From 1983, a carcass monitoring program (reviewed in Lesage et al., 2014) documented 472 deaths, 222 of which were investigated through necropsies. Of the 222 carcasses that were examined, human activities were directly responsible for about 5%; other causes included entanglement in fishing gear (1%; $n = 2$) and vessel strikes (4%; $n = 8$). Cause of death was undetermined for 55 individuals (25%). Malignant neoplasms were responsible for the deaths of 31 of the 222 belugas (14%), whereas parturition-associated complications caused the death of 22 adult females (10%). Chronic exposure to environmental contaminants is one of the hypotheses put forward to explain the unusually high occurrence of some of the pathological conditions observed in this population (Lair et al., 2016).

A model using the catch history suggested that the SLE beluga population numbered between 5,000 and 10,000 in the 1800's but only 1,000 in the late 1970's. As recently as 2007 the population was considered stable (Hammill et al.[47]), but subsequent carcass monitoring showed an increase in mortality of young-of-the-year and in perinatal mortality of adult females. This triggered a detailed review of the stock's status in 2013 (DFO[48]). A population model suggested a period of relative stability until 1999, followed by a period of demographic instability (2000–12), including peaks of high neonatal mortality interspersed with peaks of high pregnancy rates (Mosnier et al., 2015). The current view is that the population was stable or increasing very slowly (0.13%/yr) until 2000, then declined (at ~1%/yr) until 2012, reaching a population of 889 individuals in 2012. Using this estimate and a recovery factor of 0.1 (for an endangered species or population) resulted in a PBR of one.

SLE belugas live in one of North America's major commercial waterways, which means they are exposed to elevated sound levels from passing ships and boats (McQuinn et al., 2011; Gervaise et al., 2012), and the risk of being struck by ships (or more likely small boats) in some parts of their range is high (Lair et al., 2016). Whale-watching tourism sometimes is centered on belugas (Ménard et al.[49]), and this is regarded as an additional potential source of disturbance, particularly in calving and nursing areas. The stock is also exposed to numerous contaminants due to the highly industrialized nature of the St. Lawrence watershed (DFO[50]).

While the prevalence of some contaminants such as PCB's seems to have declined since the 1980's, that of others such as PBDE's has increased or remained high. Although the effects of contaminants on belugas are difficult to demonstrate conclusively, impacts on reproduction, offspring development, and immune system function have been shown in other mammals

[45]Trana, M. R. 2014. Variation in blubber cortisol as a measure of stress in beluga whales of the Canadian Arctic. MS Thesis, Dep. Biol. Sci., Univ. Manitoba.

[46]Mosnier, A., V. Lesage, J.-F. Gosselin, S. Lemieux Lefebvre, M. O. Hammill, T. Doniol-Valcroze. 2010. Information relevant to the documentation of habitat use by St. Lawrence beluga (*Delphinapterus leucas*), and quantification of habitat quality. DFO Can. Sci. Advis. Sec., Res. Doc. 2009/098. iv + 35 p. (avail. at http://www.dfo-mpo.gc.ca/csas).

[47]Hammill, M. O., L. N. Measures, J.-F. Gosselin, and V. Lesage. 2007. Lack of recovery in St. Lawrence estuary beluga. DFO Sci. Advis. Sec., Res. Doc. 2007/026. 19 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/)

[48]DFO. 2014. Status of beluga (*Delphinapterus leucas*) in the St. Lawrence River estuary. DFO Can. Sci. Advis. Sec. Sci., Advis. Rep. 2013/076 (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[49]Ménard, N., R. Michaud, C. Chion, and S. Turgeon 2014. Documentation of maritime traffic and navigational interactions with St. Lawrence Estuary beluga (*Delphinapterus leucas*) in calving areas between 2003 and 2012. DFO Sci. Advis. Sec., Res. Doc. 2013/003. v + 24 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[50]DFO. 2012. Recovery strategy for the beluga whale (*Delphinapterus leucas*), St. Lawrence Estuary population in Canada. Species at Risk Act Recovery Strategy Ser. Fish. Oceans Can., Ottawa. x + 87 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

(Martineau, 2010; Lair et al., 2016). Cancer rates in these belugas are extremely high (20% in individuals more than 19 years old; Lair et al., 2016). Environmental perturbations such as recurrent harmful algal blooms are suspected to be affecting SLE belugas as well. For example, a bloom in 2008 was implicated in the deaths of seven animals (both adults and calves) in one week (Scarratt et al.[51]). Moreover, a study combining several physical and biological indices indicated that the quality of beluga habitat has been relatively poor since the late 1990's and may have worsened since 2009 (Plourde et al.[52]).

Workshop Discussion

There appears to be considerable inter-annual variation in reproductive output in SLE belugas. The variable rates of pregnancy and calf mortality may be related to the cumulative effects of several environmental stressors. For example, harmful algal blooms in combination with contaminants may affect belugas in some years, whereas in other, less stressful years, reproduction may improve.

Concerns were expressed regarding the potential impacts of whale-watching, an activity that is not permitted within designated beluga critical habitat but is unrestricted in other areas where belugas are often found. Aspects of unregulated whale-watching may contribute to cumulative impacts.

Status

There is a high level of concern for this stock owing to its small size, declining trend, and chronic exposure to relatively intense industrial activity and other commercial activities in much of its range.

19) Southwest Greenland (Extirpated)

The Southwest Greenland beluga stock, which is effectively extirpated, migrated south in autumn, arrived in Nuuk between October–December, and went at least as far south as Qeqertarsuatsiaat (Fiskenæsset). These belugas were also frequent visitors to South Greenland in the 19th century, which is confirmed by reports and catch statistics. Large numbers were also seen in winter in fjords between lat. 61° N and lat. 63° N, although the main distribution was farther north in Nuuk and Maniitsoq. The northward migration started in February and the last individuals left the southern districts by June or July (Winge, 1902; Møller, 1928; Møller, 1964). Degerbøl and Nielsen (1930) mentioned another pulse of migrating whales arriving in South Greenland in December. These were apparently fatter and in better condition and sometimes had fresh bullet wounds. It is possible that these animals were of Canadian origin.

There were large catches of belugas in Greenland from the middle and late 1800's until the late 1920's (Heide-Jørgensen, 1994). The largest catches (up to 1,500 individuals in a single year) were in Maniitsoq, but Nuuk also had large catches. The hunting season in Nuuk was mainly in spring and early summer. In the 20th century, the whales were caught by netting and driving. In Maniitsoq, driving started in 1917. The cumulative catch in Maniitsoq between 1917 and 1930 was 8,000–10,000 belugas. During this time, most of the catches were of whales on their southward migration, whereas previous catches had been mainly of animals on their northward migration.

Møller (1928) stated that the occurrence of belugas in Godthåb Fjord crashed, and after 1920 they left the fjord earlier in the spring and were caught only occasionally. A decline in catches was evident during the late 1920's (Heide-Jørgensen, 1994). Following this decline, local people in Greenland referred to a change in the timing of migration of belugas from Uummannaq and Upernavik. Some local people claimed that the disappearance of belugas from Nuuk and Maniitsoq was due to changes in sea temperatures after 1926.

Workshop Discussion

The hypothesis that there was a connection between the extinct stock of belugas in Southwest Greenland and the Cumberland Sound stock in Canada might be investigated further with DNA from museum specimens. Belugas are occasionally reported, on average one per year, in the historical migration and hunting areas of this stock, but systematic surveys for large whales, while regularly sighting harbor porpoises, *Phocoena phocoena*, do not find belugas in these areas (Hansen et al., 2019).

Status

This stock was likely extirpated more than 80 years ago.

20) Svalbard

The Svalbard stock of belugas inhabits coastal waters of the Svalbard Archipelago during ice-free months, and the whales are thought to occupy nearby offshore areas adjacent to Svalbard in winter. Telemetry data show that Svalbard belugas are extremely coastal in their distribution during the ice-free season. They spend most of their time close to glacier fronts, and when they move from one front to another, they do so in an apparently directed and rapid manner very close to shore (Lydersen et al., 2001).

When sea ice forms in winter, the whales move offshore somewhat but still stay in the Svalbard area (mostly to the southeast of the archipelago), often occupying areas with more than 90% ice cover (Lydersen et al., 2002). A multi-species cetacean survey in the marginal ice zone north of Svalbard during August 2015 detected no belugas, only bowhead whales, *Balaena mysticetus*, and narwhals (Vacquié-Garcia et al., 2017). However, during

[51]Scarratt, M., S. Michaud, L. Measures, and M. Starr. 2014. Phytotoxin analyses in St. Lawrence Estuary beluga. DFO Can. Sci. Advis. Sec., Res. Doc. 2013/124 v + 16 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[52]Plourde, S., P. Galbraith, V. Lesage, F. Grégoire, H. Bourdage, J.-F. Gosselin, I. McQuinn, and M. Scarratt. 2014. Ecosystem perspective on changes and anomalies in the Gulf of St. Lawrence: a context in support to the management of the St. Lawrence beluga whale population. DFO Can. Sci. Advis. Sec., Res. Doc. 2013/129. vi + 27 p. (avail. at http://www.dfo-mpo.gc.ca/csas).

the same time period belugas were observed (as is normal) along the coast of Svalbard, further documenting the lack of affiliation with drifting sea ice for this whale species in Svalbard during summer.

A study of genetic differences between the belugas around Svalbard and those in West Greenland revealed limited gene flow over ecological time (O'Corry-Crowe et al., 2010). The same study suggested that Svalbard and Beaufort Sea belugas diverged 7,600–35,000 years ago, but experienced recurrent periods with gene flow since then, most likely via the Eurasian Arctic during warm periods.

There is no abundance estimate or trend information, and the status of this stock is unknown. It is classified as Data Deficient on the Norwegian Red List. A first-ever dedicated survey was planned for July–August 2018. Belugas in Svalbard have been totally protected since the 1960's, with no removals allowed. Prior to being given protected status, they were hunted heavily in commercial operations and were certainly depleted at the time when protection came into place (Gjertz and Wiig, 1994).

The impacts of climate change on sea-ice conditions, prey base composition, competition from more boreal marine mammal species, and exposure to parasites and diseases are general concerns. Levels of some pollutants in belugas from Svalbard are also very high, with the levels of many compounds being higher than those found in polar bears, *Ursus maritimus*, in the region (Andersen et al., 2001, 2006; Wolkers et al., 2004, 2006; Villanger et al., 2011). These levels are in many cases also higher than what has been shown to affect the physiology and especially the immune systems of laboratory animals. A diet study based on analyses of fatty acids in the blubber of Svalbard belugas found the composition to be most similar to that of Arctic cod, *Boreogadus saida* (Dahl et al., 2000).

Status

There was moderate concern about this stock because of the lack of information (specifically on abundance, though this was expected to change following the planned 2018 survey), the high tissue levels of pollutants, and the possible impacts of climate change.

21) Barents-Kara-Laptev Seas

The information on belugas in the Barents, Kara, and Laptev seas (Franz Josef Land, Ob Gulf, Yenisey Gulf, and southwest Laptev Sea) presented in previous assessments (IWC, 2000; Belikov and Boltunov, 2002; Boltunov and Belikov, 2002) was based on the expert opinion of the two scientists with access to limited opportunistic data, which are now outdated. Sightings data from 2001 to 2016 also came mostly from opportunistic observations during oil/gas exploration, tourist cruises, and scientific expeditions. Based on this information, belugas are thought to concentrate in summer mostly in the estuaries of large rivers (Ob, Yenisey) and in the waters of the archipelagos (Franz Josef Land, south of Novaya Zemlya, Severnaya Zemlya). Satellite tracking of a single individual tagged in north-eastern Ob Gulf (Kara Sea) was consistent with the hypothesis that during summer and autumn these belugas stay mostly in shallow coastal waters. No data are available on migratory routes. Most of the recent observations of belugas in winter were in the Kara Sea. The winter distribution likely depends at least partly on ice conditions (polynyas and ice cracks) which in turn could be influenced by icebreaker traffic, and consequently increased observation effort, in certain areas.

Analysis of mtDNA was carried out on samples from 21 belugas either found dead or harvested between 1940 and 1960 or 2012 and 2015. Most of the samples were from the Kara Sea and one was from the Laptev Sea. The analysis revealed mitochondrial haplotypes in common with or similar to those of belugas in Svalbard, the Chukchi Sea, and the Bering Sea (Meschersky et al., 2018). However, the number of genetic samples from the Russian Arctic is too limited to determine structure within this stock. There are likely several different aggregations in the major bays, estuaries, and archipelagos that could be considered stocks if more information was available.

Habitat concerns include rapidly increasing development and shipping activity in the region; there is also increased military activity in Franz Josef Land and possibly other parts of the region. Major anthropogenic threats include oil/gas (Barents and Kara seas) and military (Wezeman[53]) (all seas) activities, increasing vessel traffic (oil/gas fleet, tourism, military, shipping on the Northern Sea Route), and chemical and radioactive contamination from river discharges.

Workshop Discussion

There is not enough information to delineate stocks in the western and central Russian Arctic except within the White Sea (see item 22 below). Belugas appear to have a broad distribution across the entire region, likely at low densities in many areas, with concentrations around Franz Josef Land and in some river mouths. There is no information on current abundance or trends, genetic differences, or movements, and only limited information on distribution. Many of the aggregations in this region may have been depleted by historical commercial exploitation. Although genetic structure within the region is likely to exist, it will be difficult to delineate without additional information and samples.

There is no information to suggest a link between belugas in this area to Svalbard belugas other than that they share some haplotypes (Glazov et al.[54]). Satellite-tracked belugas remained near Svalbard through the summer, indicating geographical separation between

[53]Wezeman, S. T. 2016. Military capabilities in the Arctic: A new cold war in the high north? SIPRI (avail. at https://www.sipri.org/sites/default/files/Military-capabilities-in-the-Arctic.pdf).

[54]Glazov, D. M., O. V. Shpak, I. G. Meschersky, D. M. Kuznetsova, V. V. Krasnova, and M. V. Gavrilo. Revision of information on the white whale (*Delphinapterus leucas*) population in the White, Barents, Kara and Laptev seas. Unpubl. ms.

the Svalbard and Russian stocks at least during the summer (Lydersen et al., 2001). Quotas set by Russian authorities for allowable removals of belugas in the Arctic are reportedly based on information prior to 1995, and no more recent information on abundance (or catch levels) is available.

Status

The concern level is high for belugas in the western and central Russian Arctic, in part because little is known about stock structure, movements and distribution, current abundance (numbers may be depleted), and removals, and in part because of the rapid increase in development and other human activity as the Northern Sea Route becomes more accessible for navigation.

22) White Sea

Data on distribution and movements (from stationary coastal observation sites, ship-based and aerial surveys, satellite tracking) suggest that belugas in the White Sea form a resident population which consists of several aggregations (Andrianov et al., 2009; Kuznetsova et al., 2016; Glazov et al.[54]; Chernetsky et al.[55]; Alekseeva et al.[56]; Glazov et al.[57]; Glazov et al.[58]; Svetochev and Svetocheva[59]). Field observations indicate that White Sea belugas occur in discrete summer aggregations associated with major bays: Onezhsky, Dvinskoy, and Mezen'sky. However, more data are necessary to understand population structure in detail.

Data on abundance in different seasons were obtained from aerial surveys in 2005–11. The lowest (minimum) summer abundance estimate from these surveys was more than 5,000 animals (Glazov et al.[58,60,61]). The winter (March) estimates were 3.5–4 times lower than the July estimates in the corresponding years. Reports on earlier surveys do not contain enough information on survey design, analysis methods, and area coverage to assess population trends. The estimates from the six surveys conducted from 2005 to 2011 show a slight decline within this period, but the general pattern is variable from year to year (Glazov et al.[54]).

Records of hunting from this population go back to the 15th century (Alekseeva[62]). Commercial hunting of belugas ended in the White Sea in the 1980's (Matishov and Ognetov, 2006). In recent years, small numbers have been live-captured in the Varzuga River mouth for scientific research and "cultural display" purposes (exact numbers are unavailable, but usually not more than five or six were taken during a given capture operation). No information is available on illegal killing of belugas by local people. If this occurs at all, it probably does not exceed several whales in a year (Glazov et al.[54]). The total allowed take of belugas in the White Sea, issued annually by the Ministry of Agriculture, has been 50 for at least the last five years. No information is available on incidental mortality.

Concerns include direct disturbance of nursery aggregations by tour boats and other boat traffic, conflict with salmon fishermen, coastal oil storage bases and oil transport, and pollution, mostly from discharges from the Severnaya Dvina River. No official status is assigned to this stock, but the general opinion of Russian scientists is that the White Sea stock should be closely monitored due to the increasing human activity and high pollution levels in the region. Certain resident nursery groups of belugas, especially the one near Bolshoy Solovetsky Island (Solovetskoe local aggregation), require special protection.

Genetic information regarding White Sea belugas is limited. However, a study comparing Svalbard, West Greenland, and a few samples from the White Sea suggested some level of divergence between the White Sea and the other Atlantic strata (O'Corry-Crowe et al., 2010). Many of the mtDNA haplotypes previously documented in the Beaufort Sea and the Canadian High Arctic were also found in Svalbard and the White Sea, although one unique haplotype was found in the White Sea.

[55]Chernetsky, A. D., V. M. Belkovich, and V. V. Krasnova. 2002. New data on population structure of white whales in the White Sea. Marine Mammals of Holarctic: Materials of The 2nd International Conference, Lake of Baikal, Russia, Sept. 10–15, 2002: 279-282 (avail. at http://marmam.ru/upload/conf-documents/mmc2002_full.pdf).

[56]Alekseeva, Ya. I., V. V. Krasnova , R. A. Belikov, and V. M. Bel'kovich. 2012. The comparative characteristic of three regular summer gathering of belugas (*Delphinapterus leucas*) in the White Sea. Marine Mammals of Holarctic: Collection of scientific papers of the 7th Intl. Conf., Suzdal, Russia, 24–28 Sept. 2012, Vol. 1: 33-37 (avail. at http://marmam.ru/upload/conf-documents/mmc2012_full.pdf).

[57]Glazov, D. M., V. I. Chernook, E. A. Nazarenko, K. A. Zharikov, O. V. Shpak, and L. M. Mukhametov. 2010. Summer distribution and abundance of belugas in the White Sea based on aerial survey data (2005–2008). Marine Mammals of Holarctic: Collection of scientific papers of the 6th Intl. Conf., Kaliningrad, Russia, 11–15 Oct. 2010:134–140 (avail. at http://marmam.ru/upload/conf-documents/mmc2010_full.pdf).

[58]Glazov, D. M., O. V. Shpak, D. M. Kuznetsova, D. I. Ivanov , L. M. Mukhametov, and V. V. Rozhnov. 2012. Preliminary results of tracking the beluga whale (*Delphinapterus leucas*) movements in the White Sea in 2010–2011. Marine Mammals of Holarctic: Collection of scientific papers of the 7th Intl. Conf., Suzdal, Russia, 24–28 Sept. 2012:172–177 (avail. at http://marmam.ru/upload/conf-documents/mmc2012_full.pdf).

[59]Svetochev V. N., and O. N. Svetocheva. 2012. Study of marine mammals in the White and Barents seas using satellite telemetry: results and prospects Marine Mammals of Holarctic: Collection of scientific papers of the 7th Intl. Conf., Suzdal, Russia, 24–28 September, 2012, Vol. 2:209–213 (avail. at http://marmam.ru/upload/conf-documents/mmc2012_full.pdf).

[60]Glazov, D. M., V. I. Chernook, K. A. Zharikov, E. A. Nazarenko, L. M. Mukhametov, and A. N. Boltunov. 2008. Aerial surveys of white whales (*Delphinapterus leucas*) in July in the White Sea (2005–2007), distribution and abundance. Marine Mammals of the Holarctic. Collection of Scientific Papers. Odessa, p. 194–198 (avail. at http://marmam.ru/upload/conf-documents/mmc2008_full.pdf).

[61]Glazov, D. M., E. A. Nazarenko, V. I. Chernook, D. I. Ivanov, O. V. Shpak, and B. A. Solovyev. 2010. Assessment of abundance and distribution peculiarities of beluga whales (*Delphinapterus leucas*) in the White Sea in March 2010. Marine Mammals of Holarctic: Collection of scientific papers of the 6th Intl. Conf., Kaliningrad, Russia, 11–15 Oct. 2010:140–145 (avail. at http://marmam.ru/upload/conf-documents/mmc2010_full.pdf).

[62]Alekseeva, Ya. I. 2008. The history of harvest of marine mammals of the White Sea–Barents Sea region (15th century through 1915). Marine Mammals of Holarctic: Collection of scientific papers of the 5th Intl. Conf., Odessa, Ukraine, 14–18 October, 2008:35–38 (avail. at http://marmam.ru/upload/conf-documents/mmc2008_full.pdf).

Workshop Discussion

Although the IWC review listed three stocks of belugas in the White Sea (IWC, 2000), and subsequent notes and publications have recognized up to eight different aggregations (Chernetsky et al.[55]), more data are needed to determine whether, and how, stocks in this region should be separated. Genetic studies have detected differences between belugas in the Varzuga River estuary and Onezhysky Bay (Meschersky et al., 2018), but these differences are not significant due to the small sample sizes. Additionally, researchers in the area note that there is movement between the bays, and that these belugas all appear to remain in the White Sea throughout the winter.

Status

The White Sea stock appears to be stable, but it is of moderate concern. The main reasons are the insufficiency of data (specifically the uncertainty around stock structure) and habitat concerns related to pollution (especially discharge from the Severnaya Dvina River), ship traffic (Arkhangelsk is one of the major ports for Northern Sea Route traffic), and tourism.

Narwhals

Overall Introduction

Narwhal distribution is centered in the Atlantic Arctic. Narwhals are most numerous in the eastern Canadian Arctic and along the west coast of Greenland, but they are also found in low densities in East Greenland and the northern parts of the Svalbard and Franz Josef Land archipelagos. There are rare sightings outside this range, particularly in both High Arctic Russian and Alaska waters (Fig. 2: distribution map). Narwhals are mostly migratory and closely associated with the seasonal distribution of sea ice.

Narwhals have remarkably low levels of genetic diversity based on mtDNA (Palsbøll et al., 1997), a condition which may date back 50,000 years (Garde[63]). The low levels of genetic variability in populations in Greenland and Canada suggest a bottleneck in "recent" history (Palsbøll et al., 1997). Studies using ancient DNA to determine when this bottleneck occurred and to infer the reasons behind it continue. While it is possible to distinguish different populations of narwhals on a broad scale (e.g., Baffin Bay vs. East Greenland), it is currently not possible, due to the lack of genetic diversity, to tease apart stocks on smaller scales (e.g., to differentiate separate stocks within Baffin Bay). New genomic sequencing techniques may be used for this purpose in the future.

Stable isotope analyses of carbon (δ13C) and nitrogen (δ15N) found that the tissues of narwhals from three narwhal populations—Baffin Bay, Northern Hudson Bay, and East Greenland—have distinct stable isotope values, suggesting that these populations feed on different prey (Watt et al., 2013).

Narwhals are migratory, and the concept of "summer aggregations" has been used as the primary basis for identifying separate stocks, particularly in Baffin Bay (Heide-Jørgensen et al., 2013b). The workshop recognized 12 stocks of narwhals (Fig. 2, Tables 1–3), and this list is compared with those produced by previous assessments in Table 4.

Extralimital sightings (or what may be changes in narwhal distribution and movements in response to changing environmental conditions) have become more frequent in recent years in the Inuvialuit Settlement Area of the eastern Beaufort Sea, which is further west than the normal distribution of the closest stock, the Somerset Island stock. In addition, there have been a few scattered sightings in eastern Siberia, and along the north coasts of Chukotka (including a few tusks found) and Alaska. It is unknown whether narwhals sighted in these latter areas are from the East Greenland population to the west or instead the Baffin Bay population to the east.

Baffin Bay Introduction

Baffin Bay narwhals are divided into eight stocks, or summer aggregations, that migrate between, and are susceptible to hunting in, Greenland and Canada. These stocks are: Somerset Island, Eclipse Sound, Admiralty Inlet, Eastern Baffin Island, Jones Sound, Smith Sound, Inglefield Bredning, and Melville Bay. All of these whales were treated as a single regional stock in the 1999 IWC review (IWC, 2000; Table 4); however, since that time tagging studies have demonstrated fidelity to summering areas, and management has treated the summer aggregations as stocks. A bilateral management body, the Canada/Greenland Joint Commission on the Conservation and Management of Narwhal and Beluga (JCNB), is responsible for managing the exploitation and ensuring conservation of these narwhals. To this end, the JCNB provides advice on research, conservation, and management of narwhals and belugas to the management bodies of the two countries. The JCNB Scientific Working Group meets jointly with the NAMMCO Scientific Committee Working Group on the Population Status of Narwhal and Beluga in the North Atlantic.

The NAMMCO-JCNB Joint Scientific Working Group has developed a "catch-allocation model" to assign the catches of narwhals, by season and for different hunting communities in Canada and Greenland, to stocks (NAMMCO[64]). The model is based on information concerning narwhal seasonal movements (e.g., from satellite tracking, local and expert knowledge of hunters and scientists from Greenland and Canada) and hunting locations, so that takes by communities that hunt both on a summer aggregation and on migrating narwhals

[63]Garde, E. 2011. Past and present population dynamics of narwhals *Monodon monoceros*. PhD Dissert., Faculty Sci., Univ. Copenhagen, 2011, 252 p.

[64]NAMMCO. 2015. NAMMCO-JCNB Joint Scientific Working Group on Narwhal and Beluga, 11–13 March 2015, Ottawa, Canada (avail. at http://nammco.wpengine.com/wp-content/uploads/2016/09/JCNB-NAMMCO-JWG-March-2015-Main-Report-FINAL.pdf).

during fall, winter, or spring are assigned appropriately. Where more than one stock is thought to be migrating past a community in the same season, the takes are allocated on the basis of the relative sizes of the two (or more) stocks (Watt et al., 2019).

The NAMMCO catch-allocation model is used with a multi-stock risk assessment model which uses population dynamics models for each of the eight summer aggregations simultaneously (Witting et al., 2019). In an iterative process, the eight populations are projected forward one year (i.e., one year of growth), then the allocation model is updated and the removals (landings + struck-but-lost) from that year are allocated and removed from the stocks to get the population sizes after accounting for hunting. The process is then repeated for the next year. Management advice is derived from this risk assessment process which uses a Bayesian framework and estimates the population parameters and the probability of decline under various removal levels. A few of the Baffin Bay summer aggregations have just one abundance estimate and no information on trends to inform the models. For these data-poor stocks, a PBR is calculated post hoc using the abundance estimated by the model to provide an alternative to the management advice based on the model.

The multi-stock risk assessment model, i.e., the combined population dynamics and catch-allocation model, can be used to determine where more research, such as satellite tracking or updated abundance estimation, is needed and to assess the benefits of such research in the form of improved management advice. The ability to assign individuals to their appropriate summer aggregation via genetic or other data would greatly improve the input data for the allocation model.

1) Somerset Island

The Somerset Island (SI) narwhal stock is defined on the basis of a consistently observed summer aggregation in Peel Sound in late July–early August according to local knowledge, telemetry tracking, aerial surveys, genetics, and stable isotopes. The SI stock is the largest narwhal stock in terms of both area of distribution and number of whales. The summering area includes Prince Regent Inlet and the Gulf of Boothia, Peel Sound, Barrow Strait, and northern Foxe Basin, and in recent years the summer distribution has occasionally extended west to the Cambridge Bay area. Satellite-tagged narwhals remained in the Somerset region during summer and returned there after spending the winter in an area of Baffin Bay slightly north of where other summer aggregations spend the winter (Heide-Jørgensen et al., 2003a; Dietz et al., 2008). There is some genetic support for delineation of this stock (Petersen[4]) and stable isotope values from skin samples differ from some of the other Baffin Bay whales hunted in other regions, suggesting a degree of separation based on foraging (Watt et al. [5]).

The most recent (2013) abundance estimate for the SI stock is 49,768 (CV=0.20), including a correction for perception bias using mark-recapture line transect data collected during the survey and an availability bias correction factor of 2.94 (CV =1%) for water with visibility to 2 m depth based on dive data from 27 tagged narwhals (Doniol-Valcroze et al.[65]). This stock, or portions of it, were surveyed in 1981, 1984, 1996, 2002–2004, and 2013, and results of the five surveys conducted over the past 30 years suggest an increasing stock (Witting et al., 2019; NAMMCO[64]).

In Canada, the SI stock is hunted primarily during summer in the central Canadian Arctic by hunters from Gjoa Haven, Hall Beach, Igloolik, Kugaaruk, Resolute/Creswell Bay, and Taloyoak (Heide-Jørgensen et al., 2013b); however, hunters from other communities can hunt these whales on their migration to and from the summering areas in Nunavut and in the wintering areas off Greenland (NAMMCO[64]) (see below).

The current Canadian quota known as Total Allowable Landed Catch (TALC) is set at 532 for this stock, based on the abundance estimate from the 2002 survey, whereas a new recommendation (which has not yet been implemented) based on the 2013 aerial survey results is for a TAT of 658. The reported annual take (including estimated struck-but-lost using a multiplier based on observations of open-water hunting) in the summer during 1970–2015 ranged from 0 to 220 whales.

The SI stock is hunted in its winter habitat off Greenland. Ninety-seven percent of the Greenland harvest of this stock is by Uummannaq hunters (yearly quota=61). Narwhal catches in some years prior to the introduction of the quota at Uummannaq in 2004 were close to 1,000 animals (e.g., 1990).

Removals from this and other stocks in the Baffin Bay population are now managed according to the NAMMCO-JCNB catch-allocation model and are considered sustainable[64]. Despite the quota for Uummannaq, attention is still needed to document and/or reduce struck-but-lost rates in this area. Another aspect needing attention is that substantial numbers of animals from this stock are taken in the floe-edge and ice-crack hunts at Pond Inlet and Arctic Bay, which can have relatively high associated loss rates.

Habitat concerns include increased shipping and icebreaking in the Northwest Passage, much of it to service development activities in the region. Reduction of sea ice and other changes resulting from climate warming in the Arctic are other concerns.

Workshop Discussion

This is the largest narwhal stock, numbering around 50,000 animals. The summer distribution is extremely variable, depending on pack-ice movements as narwhals with young calves show a strong preference for staying near the ice. It is likely that this stock will be subdivided as more becomes known about it, given the vast summer

[65]Doniol-Valcroze, T., J. F. Gosselin, D. Pike, J. Lawson, N. Asselin, K. Hedges, and S. Ferguson. 2015. Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/060. v + 36 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/Library/362110.pdf).

range in the Canadian Arctic that is currently attributed to this stock.

In recent years, because of reduced sea ice (possibly exacerbated by icebreaking) narwhals presumed to be from this most western Canadian stock have been appearing more regularly and in larger numbers in settlements to the west of Somerset Island. This has required reallocation of the quota tags used to control and monitor removals by Canadian hunters. According to residents of the Gulf of Boothia region (Kugaruuk—formerly Pelly Bay), whose communities were formerly supplied by aircraft, in recent years icebreaking ships have been used instead and this has resulted in narwhals appearing there more regularly than in the past, presumably because they took advantage of leads and cracks created by the icebreakers.

Status

Although removals are significant, they appear to be sustainable given the large size of the stock. There is no evidence that the stock is depleted. There are environmental concerns related to the loss of sea ice, icebreaking, and industrial development in some areas. Overall, there is a low level of concern for this stock.

2) Jones Sound

Narwhals in Jones Sound are genetically distinguishable from other Canadian stocks, and from those sampled in Inglefield Bredning, Greenland (Petersen et al.[4]). Thus, they are considered a distinct stock. Additionally, organochlorine contaminant profiles in whales sampled in Grise Fiord, which are believed to be part of the Jones Sound stock, were notably different from whales sampled in Pond Inlet from the Eclipse Sound stock (de March and Stern[2]). Little is known about movements or dive behavior of narwhals in Jones Sound since there have been no telemetry studies there.

An aerial survey conducted in 2013 resulted in an abundance estimate of 12,694 (CV = 0.33) narwhals (Doniol-Valcroze et al.[65]). This is the only survey that has been conducted in the area occupied by the Jones Sound stock, and no trend information is available.

In the Jones Sound region, the stock is hunted primarily by Inuit of Grise Fiord in summer (Heide-Jørgensen et al., 2013b). A recommended TALC of 40 has been in place since 2013, but fewer than 20 narwhals/yr have been landed by Jones Sound hunters since then. Hunters from other communities (including those in Greenland) may hunt these whales along their migration route to and from the summer range, and on the winter range. However, there are no satellite-tagging data from Jones Sound, and the migration corridors and winter range of these whales are not known.

Workshop Discussion

The only current habitat concern for the Jones Sound stock is the loss of sea ice, although the possible development of a coal mine on northern Ellesmere Island was discussed in Canada several years ago. It is likely that additional development projects will occur in the area in the future as sea ice continues to decline.

Status

The level of concern for this fairly large stock of around 12,000 animals, which is not heavily hunted, is low. There is little development in the region thus far, although this is likely to change as sea-ice conditions change.

3) Smith Sound

Stock identity of Smith Sound narwhals is based on observations and catches of narwhals there during summer. Tissue samples have not been collected and very limited telemetry studies have been carried out on narwhals in Smith Sound; thus their relationship to narwhals in Inglefield Bredning is uncertain.

An aerial survey in 2013 resulted in an abundance estimate of 16,360 (CV=0.65) for the Smith Sound stock (Doniol-Valcroze et al.[65]). As this is the only survey that has been conducted in Smith Sound, there is no information on trend.

Little is known about the movements or total range of narwhals that occupy Smith Sound seasonally. A male tagged along the ice edge at Rensselaer Bay on the Greenland side of the sound was tracked for only three days, during which time it moved across Smith Sound to Cape D'Urville on the Canadian side (Heide-Joergensen[66]).

No communities in Canada are known to hunt narwhals from the Smith Sound stock, although the stock is hunted by Greenlandic hunters from Qaanaaq. A TALC of 77/yr was recommended in Canada based on the abundance estimate from the 2013 survey. The current quota for narwhals taken from the Smith Sound stock in Greenland (Etah hunting region) is 5/yr.

There is a small amount of development in the area, and future development possibilities exist.

Workshop Discussion

In the complete absence of sampling and analysis, there is no basis, other than geographical, to differentiate the Smith Sound stock from other narwhal stocks such as the Inglefield Bredning or Jones Sound stock.

Status

As with the Jones Sound stock, there is low concern for this fairly large stock (around 16,000 animals) that is apparently subjected to little hunting.

4) Admiralty Inlet

The Admiralty Inlet (AI) stock is defined on the basis of a consistent summer aggregation reported via local knowledge, telemetry tracking, and aerial surveys. Satellite-tagged narwhals have remained in Admiralty Inlet during summer and returned there after spending winter in the Baffin Bay region (Dietz et al., 2008; Watt et al.[6]). There is no strong genetic support for delineation of this stock; however, stable isotope values from skin samples differed significantly from those of

[66]Mads Peter Heide-Jørgensen, Greenland Institute of Natural Resources c/o Greenland Representation, Strandgade 91, 2. sal, 1401 København K, Denmark.

whales in other regions, indicating a degree of separation based on foraging tendencies (Watt et al.[5]).

The most recent (2013) abundance estimate for the AI stock was 35,043 (CV=0.42), including a correction for perception bias using mark-recapture line transect data collected during the survey and an availability bias correction factor of 2.94 (CV =1%) for water with visibility to 2 m depth based on dive data from 27 tagged narwhals (Doniol-Valcroze et al.[65]). Five surveys of the AI stock have been conducted over the past 30 years, with no indication of a significant change in abundance over time (Richard et al., 2010; Witting et al., 2019; Asselin and Richard[67]).

The AI stock is hunted primarily by the community of Arctic Bay (Heide-Jørgensen et al., 2013b). However, hunters from other communities hunt these whales on their migration to and from the summer range and on the winter range (Watt et al., 2019). While the current TALC for this stock is 233, based on the abundance estimate from the 2010 survey (DFO[68]), the recommended TALC based on the 2013 aerial survey is 389 whales (Doniol-Valcroze et al.[65]). The reported annual removals (including struck-but-lost estimates applied for open-water hunting) from the summer hunt during 1970–2015 ranged from 32 (in 1987) to 276 (in 2015) whales, with an average of 181 per year for the 10-yr period between 2006 and 2015. The stock is also hunted on the winter range in Greenland, where 2% of the landed catch in Uummannaq (yearly quota=61) is from the AI stock and 32% of the landed catch in Disko Bay (yearly quota=108) consists of AI animals (NAMMCO[64]).

The distribution of the AI narwhal stock likely overlaps that of the Eclipse Sound (ES) stock in summer. The AI and ES stocks were both surveyed in 2010 and 2013. The sums of the abundance estimates for the two stocks were similar in 2010 and 2013. However, the AI estimate increased between 2010 and 2013 by approximately the same amount as the ES estimate decreased, suggesting that narwhals counted in the ES stock in 2010 moved to AI prior to the survey in 2013. Also, 4 of 12 narwhals tagged during summer in Eclipse Sound in 2010 and 2011 traveled into Admiralty Inlet in September/October of the same year (n = 3), or during the following summer (n = 1) (Watt et al.[6]). Nevertheless, a precautionary approach has been applied by continuing to manage the narwhals in AI and ES as separate stocks pending stronger evidence to support combining them. This is seen as a means of minimizing the risk of stock depletion.

Ship traffic in Baffin Bay may affect this stock in its winter range. Although abundance estimates vary across surveys, the AI stock is considered stable, and current removals are thought to be sustainable (Witting et al., 2019; NAMMCO[64]).

Workshop Discussion

This stock is hunted in summer by Inuit from Arctic Bay, at the floe edge in spring by hunters from Pond Inlet, and in at least the Disko Bay area of Greenland in winter. Hunters from Arctic Bay previously took many narwhals at the Admiralty Inlet floe edge, which included whales from both the Somerset Island and Admiralty Inlet stocks. Now much more of the Arctic Bay hunting occurs in summer, which means there is greater pressure on the Admiralty Inlet stock to supply the relatively large Arctic Bay quota.

The time series of abundance estimates suggests that this stock is fairly stable, although the estimates are quite variable across years (differing by over 10,000 animals) and have large confidence intervals.

There are concerns over increased disturbance in the summer habitat by freighters, cruise ships, and supply vessels. Closure of the Nanisivik lead-zinc mine in 2002 may have resulted in reduced icebreaking activity in and immediately outside Admiralty Inlet.

Status

In spite of the habitat concerns related to shipping and icebreaking, the concern level for this stock is low because of its relatively large size and the assumption that removal levels are sustainable.

5) Eclipse Sound

Designation of Eclipse Sound narwhals (ES) as a separate stock is supported by telemetry studies which showed that most individuals tagged in the sound stayed there through the summer and returned the following summer (Dietz et al., 2001; Heide-Jørgensen et al., 2002; Watt et al.[6]). However, one whale tagged in Eclipse Sound returned the following year to Admiralty Inlet after overwintering in Baffin Bay, and a telemetry study in 2010–11 showed that 3 of 12 narwhals tagged in Eclipse Sound during summer moved into Admiralty Inlet in September/October (Watt et al.[6]), indicating that there is some movement between the two stock areas.

The most recent (2013) abundance estimate for the ES stock was 10,489 (CV = 0.24) (Doniol-Valcroze et al.[65]). Given that only two surveys of the ES stock have been undertaken, a trend in abundance cannot be determined. In Canada, the stock is hunted primarily by the community of Pond Inlet in summer (Heide-Jørgensen et al., 2013b), but hunters from other communities in both Canada and Greenland hunt ES narwhals on their migration to and from the summer range and in the wintering areas (Witting et al., 2019; NAMMCO[64]). The current Canadian TALC is set at 236 for this stock, although a new TALC of 134 was recommended (but has not yet been implemented) based on the 2013 aerial survey results (Doniol-Valcroze et al.[65]). The reported annual removals (landed catch multiplied by a 1.28 struck-but-lost factor) by Pond Inlet hunters from 1970 to 2015

[67]Asselin, N. C., and P. R. Richard. 2011. Results of narwhal (*Monodon monoceros*) aerial surveys in Admiralty Inlet, August 2010. DFO Can Sci Advis Sec Res Doc 2011/065: iv + 26 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[68]DFO. 2012. Abundance and total allowable landed catch for the Admiralty Inlet narwhal stock in 2010. DFO Can Sci Advis Sec Sci Advis Rep 2012/048 (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

ranged from 41 (in 1972) to 256 (in 1973) narwhals, and the average for the 10-yr period from 2006 to 2015 was 130.

Like the SI and AI stocks, animals from this stock are subject to hunting at the Lancaster Sound floe edge in spring (by hunters from Pond Inlet), off eastern Baffin Island in the fall, and in West Greenland in winter.

In the wintering areas in Greenland, 1% of the landed catch in Uummannaq (yearly quota=61) and 52% of the landed catch in Disko Bay (yearly quota=108) are believed to be from the ES stock (NAMMCO[64]).

As noted earlier, the summer and autumn ranges of ES and AI narwhals may overlap. Eclipse Sound has been identified as an important area for narwhal calving (Mathewson[69]), and increased shipping and icebreaker traffic associated with mineral resource development are potential threats to this stock on both its summer and winter range.

Habitat concerns include boat disturbance from hunting, shipping, and tourism, and icebreaking. Narwhals are hunted intensively in summer in Eclipse Sound, and, in addition, they are exposed to heavy and increasing large-vessel traffic, including cruise ships and the freighters traveling to and from the Milne Inlet port for the Baffinland-Mary River iron mine. Pond Inlet experienced a threefold increase in vessel traffic between the 1990's and 2015, primarily cruise ships and transport vessels related to the iron mine (Dawson et al., 2018), which is likely to have significant impacts on the behavior and distribution of the whales in this important summer habitat (DFO[70]).

Two large ice-entrapment events, resulting in the deaths of over 900 narwhals, have been documented in the last 10 years for this stock. In 2008, over 650 narwhals were trapped and in 2015 at least 250 narwhals were trapped. Although the cause of these entrapments cannot be confirmed, it has been suggested that seismic surveys (Heide-Jørgensen et al., 2013a) and ship traffic delayed the narwhals' movements out of their summering areas, making them more susceptible to entrapment by fast-forming sea ice.

Workshop Discussion

Telemetry results and the summer residency of narwhals in Eclipse Sound constitute the basis for distinguishing between the Eclipse Sound and Admiralty Inlet stocks. There is some movement of animals between these two summering areas, including the "switching" from Eclipse Sound the first year to Admiralty Inlet the next year by the one whale whose tag continued transmitting long enough to monitor its return northward migration after being tagged in Eclipse Sound in the previous summer. Inuit in the area believe strongly that two different kinds of narwhals, which differ in appearance, visit Eclipse Sound. Additional telemetry work is therefore important to clarify movement patterns and stock delineation.

Status

Although a trend in abundance cannot be determined, this stock appears to be stable at around 10,000 narwhals and removals are thought to be sustainable. However, there is considerable uncertainty about the abundance estimates and some uncertainty about stock differentiation (from the Admiralty Inlet stock). A major and growing concern is ship traffic related to the Baffinland-Mary River iron mine and tourism. Overall, the Eclipse Sound stock of narwhals is of moderate concern.

Update

In 2017 three of nine narwhals tracked with satellite transmitters attached during August in Eclipse Sound moved to Admiralty Inlet that same month and did not return to Eclipse Sound that summer (Marcoux[71]). This shows that some narwhals use both areas during summer.

6) Inglefield Bredning

The Inglefield Bredning narwhal stock (IB) is defined on the basis of a consistent summer aggregation, aerial survey results, local knowledge, and hunting patterns. Migration timing and routes for this stock are unknown but a portion of the whales that winter in the North Water polynya (NOW) could be the same narwhals that summer in Inglefield Bredning. An aerial survey of the eastern part of the NOW conducted in April 2014 resulted in an estimate of 3,059 narwhals (95 % CI 1,760–5,316; Heide-Jørgensen et al., 2016), however the western portion was not surveyed so the total number wintering in the NOW could not be estimated.

Genetic differences have been documented between Melville Bay narwhals and narwhals from the Avernersuaq district, which includes Inglefield Bredning (Palsbøll et al., 1997). Hence, little gene flow is thought to occur between these areas.

The most recent abundance estimate for the Inglefield Bredning stock was 8,368 (cv=0.25; 95% CI 5,209–13,442) from a visual aerial line transect survey conducted in the summer of 2007 (Heide-Jørgensen et al., 2010b). The estimate was corrected for whales missed by observers using data from paired observers in a sight-resight line transect analysis and multiplied by 4.76 (CV=0.04) to account for submerged whales based on the portion of time spent above 2 m depth for two whales tagged with satellite-linked time-depth recorders. The distribution of narwhals in Inglefield Bredning was in good agreement with what was documented during aerial surveys in 1985–86 and 2001–02 (Born et al., 1994; Heide-Jørgensen, 2004).

[69]Mathewson, S. 2016. Narwhal nursery located in busy Canadian waters; are the elusive sea animals at risk? *Nature World News* (avail. at https://www.natureworldnews.com/articles/19238/20160108/narwhal-nursery-found-busy-waters-canada-elusive-sea-animals-risk.htm).

[70]DFO. 2014. Science review of the final environmental impact statement addendum for the early revenue phase of Baffinland's Mary River Project. DFO Can. Sci. Advis. Sec. Sci. Resp. 2013/024 (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

[71]Marcoux, Marianne. Dep. Fish. Oceans Canada, 501 Univ. Crescent, Winnipeg, Manitoba R3T 2N6, Canada.

Abundance estimates have been stable for this population over time. The estimated trajectory for the stock comes from a population dynamics model, based on a Bayesian framework, that is age- and sex-structured (Witting et al., 2019). According to the model, the Inglefield Bredning stock is depleted to below its Maximum Sustainable Yield Level (MSYL).

The IB stock is hunted in the Qaanaaq region during April–September (by hunters from the communities of Qaanaaq, Qeqertat, and possibly Siorapaluk). Quotas are set on the basis of the NAMMCO-JCNB catch allocation model (Watt et al., 2019). In the municipality of Qaanaaq, local hunting rules require that hand-harpoons are used to strike the whales (and thereby tether them to a drag or float) before they can be shot (harpoon-first requirement). This reduces the loss rate considerably. A loss rate of 5% is arbitrarily applied to the catches to account for both whales that are killed-but-lost and calves that lose their mothers. Annual removals averaged 112 narwhals for the 10-year period from 2005 to 2014; these include 94 animals taken from two ice entrapments so that removals by hunting averaged around 103/yr.

The total allowable take for the Inglefield Bredning stock is 98 individuals per year (2015–20), which allows for a 70% probability that the stock's abundance will be increasing by 2020.

Concerns for the IB stock include changes in the sea-ice regime, ship traffic, seismic surveys, and competition with fisheries for Greenland halibut, *Reinhardtius hippoglossoides* (Laidre et al., 2008, 2015).

Workshop Discussion

The stock appears to be stable, but there are several environmental concerns and the depletion level estimated by the model is also a concern. The depletion below MSYL indicates that future harvest levels should be set to ensure recovery to at least MSYL. Information is lacking on the distribution of this stock in winter when it may be hunted in other locations. An additional consideration, however, is that some narwhals from other stocks may still be present in the NOW when hunting begins in April, therefore it is possible that not all of those taken in the NOW are from the IB stock (Watt et al., 2019).

Status

This is a moderate-sized, apparently stable stock. While the recent average number of removals has been around 5% above the TAT for the next management period, the current removal levels are considered sustainable. Overall, the concern level for this stock is low, assuming that no major change occurs in human activities in the region.

7) Melville Bay

Stock identity of narwhals in Melville Bay (MB) is based on consistent summer aggregation, telemetry tracking, genetics, aerial surveys, local knowledge, and hunting patterns. The most recent (2014) abundance estimate for the MB stock is 3,091 (CV=0.50; 95% CI 1,228–7,783) (Hansen et al.[72]). The estimate was corrected for both perception and availability bias. The correction factor for at-surface availability was based on monitoring of five tagged whales from August to September in Melville Bay (a=0.22; CV=0.09); note that the at-surface abundance is divided by the correction in this case (equivalent to multiplying by 4.55).

Animals in this stock are hunted primarily by communities in the Upernavik region during July–October, but they are also hunted in Uummannaq during November–May and Disko Bay during December–April. Quotas were first implemented in 2004 and are now set on the basis of the NAMMCO-JCNB catch allocation model (Watt et al., 2019). During the period 2004 through 2014 total removals by hunting (including estimated struck-but-lost) averaged 305/yr. During the same period 219 narwhals were taken from three ice entrapments.

For Greenland overall, it is assumed that a struck-but-lost correction factor of 1.30 covers both the open-water hunt and the hunt from ice cracks and the ice edge (for the Melville Bay-Upernavik area a factor of 1.15 is used). Catches of whales from the MB stock are however made in both the municipality of Uummannaq and in Upernavik. Roughly half of the narwhals taken in Upernavik and Melville Bay are taken under the harpoon-first requirement (5% loss rate) and the other half are taken in ice-edge and open-water situations where the loss rate is higher (Garde et al., 2019).

The MB stock is considered depleted to below MSYL, indicating that future removal levels should be set to ensure the population will increase. The total allowable take recommended by the NAMMCO-JCNB Joint Scientific Working Group (JWG) for the MB stock is 84 individuals per year (in the period 2015–20), allowing for a 70% probability that abundance will be increasing by 2020 (NAMMCO[64]). However, quotas set by Greenland do not follow the advice of the JWG.

The greatest concern for the MB stock is that removals in the Upernavik hunting region greatly exceed the recommended limit. Habitat concerns include changes in the sea-ice regime, disturbance by commercial fishing, shipping, icebreaking associated with shipping, and seismic surveys, and resource competition with commercial fisheries for halibut in central Baffin Bay (Laidre et al., 2008, 2015).

Workshop Discussion

An important concern for this stock is quota levels that may cause the stock to decline. As this stock is considered depleted to below MSYL, future removal levels should be set to ensure recovery to at least MSYL.

Habitat concerns include increased commercial halibut fishing, and the likely eventual resumption of seismic survey activity in Baffin Bay. During 2012–14, there was extensive seis-

[72]Hansen, R. G., S. Fossette, N. H. Nielsen, M. H. S. Sinding, D. Borchers, and M. P. Heide-Jørgensen. 2015. Abundance of narwhals in Melville Bay in 2012 and 2014. NAMMCO/SC/22-JCNB/SWG/2015-JWG/14. Request from R. Hansen, Greenland Inst. Nat. Resour. c/o Greenland Representation, Strandgade 91, 2. sal, 1401 København K, Denmark.

mic survey activity in the summering area of this stock. Observational studies during those years suggested that habitat use by narwhals was affected, though estimated numbers of narwhals in the summering area pre- and post-seismic survey activity did not differ significantly (Hansen et al.[72])

Status

There is a high level of concern for this stock. The stock is small and likely overexploited (i.e., catches above recommended quotas), and it is subject to multiple potential threats besides hunting (e.g., disturbance from seismic surveys, icebreaking in winter).

8) Eastern Baffin Island

The recognition of Eastern Baffin Island (EBI) narwhals as a separate stock is based mainly on the consistent summer aggregation reported by local people. No tagging studies have been carried out on narwhals in the region. Although this stock cannot be distinguished using genetics, organochlorine contaminant (de March and Stern[2]) and stable isotope profiles (Watt et al.[5]) of the whales in eastern Baffin Island differ significantly from those of other narwhal stocks.

The EBI stock has been surveyed twice, resulting in a 2003 abundance estimate of 10,073 (CV = 0.34) and a 2013 estimate of 17,555 (CV = 0.35) (both adjusted for availability and perception biases) (Doniol-Valcroze et al.[65]). It is not possible to make a robust assessment of the trend from these data. The stock is hunted primarily by the Canadian communities of Clyde River and Qikitarjuak in summer and fall (Heide-Jørgensen et al., 2013b). Removal levels in these two communities are low, with about 130 narwhals reported as being landed per year since 2000. However, the two communities hunt narwhals primarily in autumn when animals from other stocks are migrating along the Baffin Island coastline, making it difficult to know which stock is being hunted (Watt et al., 2019). Other communities may hunt EBI narwhals during fall, winter, and spring. Their migration route is unknown but thought to be similar to those of the ES and AI stocks that migrate past eastern Baffin Island in fall, which would make them available to hunters in Greenland in winter (Watt et al., 2019). However, a tagging study is needed to confirm this. The EBI stock is quite large with no major conservation concerns at this time. However, relatively little information is available to inform stock assessment.

Workshop Discussion

This moderate-sized stock's status is uncertain in a number of ways. In the absence of satellite-tracking studies, it is not known how much movement there is among the various fjords along the Baffin Island coast, and the animals' wintering range is unknown. Different groups of narwhals may affiliate with different fjords, and therefore as more becomes known, this stock may require subdivision.

Although recent catch levels on eastern Baffin Island appear to have been sustainable and fairly constant (97 to 183 reported as landed per year, 2000–15), there is considerable uncertainty about stock structure. The TALC is currently set at 122, but annual removals in Canada have been about 160 (using a 1.23 struck-but-lost correction factor). The new TALC recommendation based on the 2013 aerial survey results is 206 for the stock. The stock is thought to be available to Greenland hunters for part of the year even though there is no direct evidence of movement between eastern Baffin Island and Greenland.

If the whales follow a migration route similar to those of the AI and ES stocks and overwinter in central Baffin Bay, they may be affected by icebreaker activity taking place in this region. Concerns have been expressed by communities in Nunavut about the effects on narwhals of seismic survey activities off the east coast of Baffin Island[73]. Also, impacts of climate change may render the fjord areas used by the whales in summer less suitable as habitat.

Status

Although the EBI stock is fairly large and reported removals are relatively low, there is moderate concern for the stock. Concerns relate mainly to the lack of data on movements and stock structure, the possibility that several stocks (rather than only one) inhabit the EBI region in summer, and the uncertainty about whether, and if so where, narwhals from this stock are hunted in Greenland.

9) Northern Hudson Bay

The Northern Hudson Bay (NHB) stock is considered distinct based on genetic differences (de March and Stern[2]; Petersen et al.[4]), telemetry results (Westdal et al., 2010), and contaminant and biomarker profiles (de March and Stern[2]; Watt et al.[5]). This stock was surveyed in the early 1980's (Richard, 1991a), 2000 (Asselin and Ferguson[74]), and 2011 (Asselin et al.[75]) but at different spatial scales, with different data collection methods (visual or photographic) and estimation procedures (e.g., whether perception and availability biases were accounted for or not). The 2011 visual survey data were reanalyzed using the methods of the visual surveys in 1982 and 2000 to improve comparability of the survey results. This yielded surface (i.e., uncorrected) estimates of 1,737 (95% CI: 1002–3011) in 1982, 1,945 (95% CI: 1089–3471) in 2000, and 4,452 (95% CI: 2707–7322) in 2011 (Asselin and Ferguson[74]). The 2011 surface number, corrected for per-

[73]'We thought no one would care': Clyde River Inuit flooded with support. Elyse Skura, CBC News, posted 29 Nov. 2016 5:38 PM CT. Last updated 30 Nov. 30, 2016 (avail. at https://www.cbc.ca/news/canada/north/supreme-court-indigenous-duty-to-consult-clyde-river-seismic-testing-1.3873059).

[74]Asselin, N. C., and S.H. Ferguson. 2013. A reanalysis of northern Hudson Bay narwhal surveys conducted in 1982, 2000, and 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/019. v + 9 p. (avail at: http://waves-vagues.dfo-mpo.gc.ca/

[75]Asselin, N. C., S. H. Ferguson, P. R. Richard, and D. G. Barber. 2012. Results of narwhal (*Monodon monoceros*) aerial surveys in northern Hudson Bay, Aug. 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/037. iii + 23 p. (avail. at http://waves-vagues.dfo-mpo.gc.ca/).

ception and availability biases, estimated abundance at 12,485 narwhals (CV = 0.26) (Asselin et al.[75])

NHB narwhals are hunted in Cape Dorset, Chesterfield Inlet, Coral Harbour, Kimmirut, Rankin Inlet, Repulse Bay, and Whale Cove (DFO unpubl. data; Watt[76]). Reported landings from this stock increased from an average of 21 (SD=8.6) whales/yr during 1979–98 to an average of 102 (SD=55) whales/yr in 1999–2001, and then declined to 83 (SD=30) during 2002–15. A Loss Rate Correction (LRC) of 1.28 has been used to account for struck-but-lost narwhals during the hunt of this stock (Asselin et al.[75]). Using the LRC gives an average of total removals of 106/yr during 2002–15. Results of the earlier surveys raised concerns about the sustainability of harvest levels; however, the abundance estimate of 12,485 narwhals in 2011 has allayed these concerns.

Modeling of the aerial survey data from the early 1980's, 2000, 2008, and 2011 using a population dynamics model with Bayesian methods and using adjustments for different survey methods suggested a rate of increase of 1.2% per year for this stock and a population size that could support a landed catch of no more than 75 narwhals per year (Kingsley et al.[77]). Another survey was planned for summer 2018.

The PBR for the NHB stock is 201 animals. With the PBR value and a LRC of 1.28, a TALC for the Northern Hudson Bay stock is 157 narwhals (Asselin et al.[75]). With the average landed catch of 83 narwhals for the period 2002–15, the current level of removal is considered sustainable. However, this region is undergoing considerable environmental change due to climate warming and loss of sea ice as well as increases in human activity (mining, shipping), which may negatively affect the stock.

Workshop Discussion

Harvest monitoring in Canada is the responsibility of local hunters and trappers organizations and the Repulse Bay hunt is generally regarded as one of the better-managed narwhal hunts. Hunters from Arviat often travel to the Repulse Bay area to hunt narwhals. Repulse Bay has relatively strict bylaws concerning hunting practices (e.g., a harpoon-first requirement) thus using the LRC of 1.28 may overestimate the struck-but-lost removals.

The loss of multi-year ice in this population's summer range means that these narwhals are increasingly vulnerable to predation by killer whales. Another concern is that shipping, often including icebreaking, is increasing rapidly in Hudson Strait. Existing or planned mines in Baker Lake and Rankin Inlet require freight shipments and visitation by resupply vessels. As the most southerly stock of narwhals in the world, the Northern Hudson Bay stock should be monitored closely for impacts of climate change and increased human activities.

Status

The NHB stock is fairly large, numbering some 12,500 animals, with no clear evidence of a trend. The current level of hunting removals is considered sustainable. Although the loss of sea ice and concomitant increases in shipping and other industrial activities are of concern, the overall level of concern for this stock is low.

10) East Greenland

The East Greenland stock of narwhals occurs along the east coast of Greenland from about lat. 64° N to lat. 72° N. In summer, the animals are found mainly in a small number of fjords and bays, the most important being the Tasiilaq Fjord (north of lat. 65° N), Kangerlussuaq Fjord (lat. 68° N), and Scoresby Sound (north of lat. 70° N), although many smaller fjords are also visited by narwhals in summer (Heide-Jørgensen et al., 2010b; NAMMCO[29]). Hunting takes place regularly only in Tasiilaq and Scoresby Sound; hunters travel to Kangerlussuaq occasionally. Reported annual landed catches have varied widely in East Greenland (Ittoqqortoormiit and Tasiilaq) with lows of 0 in 1965 and 2 in 1978 and a high of 158 in 1990; the average during 2005–17 was 77 narwhals/yr. Applying a LRC of 1.30 to the landed catch results in an estimated average of 100 removals/yr (2005–17). Aerial surveys covering areas where hunting occurs (Scoresby Sound in 1983–84, Tasiilaq to Scoresby Sound in 2008 and 2016) indicate a widely scattered population (Heide-Jørgensen et al., 2010b; NAMMCO[29]). The survey in 2016 found no narwhals south of the Kangerlussuaq area and abundance was estimated at 702 whales (CV = 0.33) down from 2759 (CV = 0.43) in 2008 (NAMMCO[78]). A decline has been observed over the past decade and reductions in the quotas (first established in 2010) have been recommended by the JWG (NAMMCO[29]). Subsequent to the GROM a workshop convened by NAMMCO in 2019 reviewed the new estimate of abundance and other observations including the apparently low reproductive rates and recommended that the quotas in the three management areas of East Greenland be set to zero (NAMMCO[78]). The catch quotas set by the Greenland government have been reduced but are higher than the recommended takes. Hunting does not fully explain the observed decline in abundance. East Greenland has experienced significant habitat changes, including a dramatic decline in sea ice and an increase in sea temperatures, with the movement of several boreal cetacean and fish species into the narwhals' habitat (Jansen et al., 2016; Hansen et al., 2019).

Workshop Discussion

Multiple environmental changes are occurring in the region, including

[76]Watt, Cortney A., Dep. Fish. Oceans Can., 501 University Crescent, Winnipeg, Manitoba R3T 2N6, Canada.

[77]Kingsley, M. C. S., N. C. Asselin, and S. H. Ferguson. 2013. Updated stock-dynamic model for the Northern Hudson Bay narwhal population based on 1982–2011 aerial surveys. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/011. v + 19 p. (avail. at: http://waves-vagues.dfo-mpo.gc.ca/).

[78]NAMMCO. 2019. Report of the ad hoc working group on narwhal in East Greenland. Sept. 2019, Copenhagen, Denmark (avail. at https://nammco.no/topics/sc-wg-reports/).

increased sea surface temperatures, rapidly retreating ice cover, and disappearance of tidewater glaciers. This may be degrading and reducing the habitat for narwhals. The arrival of temperate-zone species is likely affecting narwhals, whether through competition for prey, exposure to novel diseases, or some combination of these and/or other processes (Hansen et al., 2019). Humpback whales, *Megaptera novaeangliae,* are now regularly observed in areas where narwhals were previously present (Hansen et al., 2019). Given such changes, the indirect negative effects of climate change may overwhelm any positive effect resulting from the elimination of hunting.

Status

There is a high level of concern for narwhals in East Greenland due to the shortage of data (particularly on stock structure), low abundance, the declining trend, the likelihood of overharvest, and the numerous climate-related changes in habitat.

11) Northeast Greenland

North of Scoresby Sound, narwhals are frequently observed in Young Sound (lat. 74° N) and Dove Bay (lat. 76° N) and along the coast as far north as Nordost Rundingen (lat. 82° N) (Boertmann et al., 2009; Boertmann and Nielsen, 2010). Given the long coastline, it is possible that there are several stocks in Northeast Greenland; however, there are currently no data to determine stock structure.

The narwhals north of Scoresby Sound are protected by the Northeast Greenland National Park. No hunting takes place in marine waters along the Park's boundary and no attempt has been made to assess narwhal abundance there. Northeast Greenland is subject to exploration for oil and gas resources and small-scale seismic surveys have been conducted there over the past decade (Ahonen et al., 2017).

Workshop Discussion

This coastline is long, and it is likely that there are multiple stocks; however, there is little to no information to delineate them at this time. More information is also needed on abundance, distribution, and movements of narwhals in this region. (Update: Surveys conducted after the workshop in 2017 resulted in estimates of 1,395 narwhals (CV=0.33) in Dove Bay and 2,908 (CV=0.30) in the Greenland Sea (Reeves and Lee, 2020).

Status

There is a moderate level of concern for narwhals in Northeast Greenland. Similar to the situation for East Greenland, there is a shortage of data on abundance and stock structure, and there are climate change-related habitat concerns. Narwhals in Northeast Greenland are currently protected at least partly by the National Park. In addition to being legally protected, the narwhals have generally not been accessible to hunters due to the remoteness of their habitat and the ice coverage in this region.

12) Svalbard-Northwest Russian Arctic

Svalbard

Narwhals are only rarely observed along the coasts of Svalbard (Storrie et al., 2018). However, groups of several hundred are seen on occasion, and three juvenile narwhals from such a group were satellite-tagged in 1998 in the Wahlenberg fjord, west of Nordaustlandet. These tags operated only for short periods (4–46 days) and the whales remained relatively close to Svalbard. The two animals that moved the longest distances went to the north and east of Nordaustlandet (Lydersen et al., 2007).

There has not been a whale survey around Svalbard specifically designed to assess narwhals, but a multi-species survey in the marginal ice zone north of Svalbard in August 2015 resulted in an abundance estimate of 837 narwhals (CV= 0.50) within the 52,919 km^2 study area, with many observations close to the distal ends of the transects in very dense ice, indicating that narwhals may occur even further north (Vacquié-Garcia et al., 2017).

Effects of climate change with impacts on sea-ice conditions and prey-base composition, competition from boreal marine mammal species, and new parasites and diseases are general concerns. Also, tissue levels of some pollutants in narwhals at Svalbard are even higher than the high levels recorded in belugas or polar bears from this region (Wolkers et al., 2006).

Northwest Russian Arctic

Narwhals are seen infrequently in the Russian Arctic (Barents and Kara Seas) with the majority occurring in the vicinity of Franz Josef Land (Belikov and Boltunov, 2002). Recent information on narwhal sightings comes mostly from the annual National Park "Russian Arctic" monitoring program, as well as opportunistic observations during oil/gas geological explorations, a few scientific expeditions, and tourist cruises. Most narwhal sightings in northwestern Russia have been recorded in the waters of western Franz Josef Land from May to September with a peak in August (1990–2013) (Gavrilo and Ershov[79]; Gavrilo[80]). One sighting southeast of Franz Josef Land was made in April 2013 (Gavrilo[80]), while several sightings were recorded in the Kara Sea in autumn (September and October, 2012–13) (Rosneft[81,82]). Most sightings were of small groups with a maximum group size of around 50 whales. Presumably, narwhal movements to the waters of

[79]Gavrilo M. V., and R. V. Ershov. 2010. Notes on cetaceans of the Franz-Josef Land – Victoria region // Marine Mammals of the Holarctic. 2010. Coll. Sci. Pap., Kaliningrad, p. 120–125 (doi: https://doi.org/10.13140/2.1.3008.2248).

[80]Gavrilo, Maria. Unpubl. data: observations and data collected via pers. commun. from visitors in Franz-Josef Land. Assoc. Maritime Heritage, Icebreaker Mus., Krassin, 22, Naberezhnaya Leitenanta Shmidta, corner of 23rd Liniya, 199106 Saint-Petersburg, Russia.

[81]Rosneft. 2012. Unpubl. data on marine mammal monitoring in Rosneft license areas, provided by Rosneft to Olga Shpak and Dmitri Glazov, A. N. Severtsov Inst. Ecol. Evol. Russian Acad. Sci., 33, Leninsky Pr., 119071 Moscow, Russia.

[82]Rosneft. 2013. Unpubl. data on biological monitoring during seismic surveys in the Rosneft "Medynsko-Varandeysky" license area, provided by Rosneft to Olga Shpak and Dmitri Glazov. A. N. Severtsov Inst. Ecol. Evol. Russian Acad. Sci., 33, Leninsky Pr., 119071 Moscow, Russia.

Franz Josef Land, as with belugas in that area, are related to their feeding on Arctic cod, *Boreogadus saida* (Dahl et al., 2000). There is no information on abundance of narwhals in this region. No studies have been conducted on migratory routes or stock structure.

There have been several sightings of narwhals and discoveries of narwhal tusks in the Chukotka region in the last 20 years, and this led to listing the narwhal in the Red Book of Chukotka (Andreev et al.[83]). There is no evidence for a separate stock; rather, it is supposed that individual whales (vagrants) occasionally enter Chukotka waters. There is no traditional harvest or live-capture of narwhals in Chukotka.

Major anthropogenic threats in the Barents and Kara Seas are thought to be similar to those for belugas and include various oil/gas activities, increasing tourist and military vessel traffic (Wezeman[53]) in Franz Josef Land waters, oil/gas fleet, and other vessel and cargo traffic along the Northern Sea Route (Glazov et al.[57]).

Workshop Discussion

Narwhals are present recurrently if not regularly in this region, but there is no detailed information on their distribution, movements, stock identity, or abundance. It is not possible with the available information to determine whether there are multiple stocks and whether any of the narwhals in the region are affiliated with stocks in East or Northeast Greenland.

Most of the recent sightings of narwhals in Svalbard have been in fjords in Nordaustlandet or in Hinlopenstretet in the northeastern part of the archipelago (see Storrie et al., 2018). However, observations of individual narwhals have also occurred in recent years on the west coast of Spitsbergen (e.g., innermost Kongsfjorden and deep within Adventfjorden). Narwhals are detected regularly on passive acoustic monitoring devices to the west of Svalbard in Fram Strait (Moore et al., 2012; Stafford et al., 2012; Ahonen et al., 2017). There also seems to be a concentration of sightings around Franz Josef Land, and there are recent sightings in the Kara Sea. There are no sightings in the Laptev Sea although there has been no dedicated search effort there for narwhals and there is little traffic in the area and hence few opportunities for sightings. Most ships pass through the Laptev Sea where it is shallow and productivity is low. It is possible that narwhals are present far offshore, but at this point the gap in narwhal distribution between the Laptev Sea and the Beaufort Sea far to the east appears to be real.

The stock(s) in this area is (are) likely small but may be distributed primarily in areas that are not well surveyed. Therefore, there is considerable uncertainty regarding abundance and distribution as well as stock identity.

Status

There is moderate concern for narwhals in this region, mainly due to the lack of detailed information and the apparently low abundance. Narwhals are protected in Svalbard and throughout Russia.

Belugas and Narwhals: Global and Regional Environmental Issues

A number of threats and other issues with known or suspected impacts on monodontid stocks were identified within the background documentation and during the discussions of each stock. Here, as with the stock by stock reviews above, we include citations where reference material is available but note that in many instances it was necessary to rely on expert judgment to help characterize a given issue.

All beluga and narwhal stocks are likely to be affected to some extent, both directly and indirectly, by the rapid warming taking place in the Arctic and sub-Arctic. As the water has warmed, sea-ice cover has decreased, enabling access by humans to formerly remote areas. The resultant increase in ship traffic and other kinds of human activity is of general concern for monodontid populations (Reeves et al., 2014), as it invariably will lead to increased disturbance, habitat degradation and disruption, noise, and chemical pollution (e.g., Kovacs et al., 2011).

The changing environment also creates other challenges for belugas and narwhals, such as differences in prey availability, exposure to novel diseases and parasites, and competition from other species. The level of concern for each type of threat varies from area to area, and there are specific concerns regionally that are currently having impacts on, or likely will have impacts on, individual monodontid stocks.

In general, the northernmost stocks of belugas are of less concern than the more southern stocks. This north-south gradient may be explained largely by the greater intensity and broader range of human activities in lower latitudes, and the effects of climate change. However, the largest beluga stock, centered in western Hudson Bay, is "southern" and apparently robust. The diet of belugas is quite diverse and they use various types of habitat. Their apparent flexibility could make belugas more resilient to Arctic warming than some other Arctic species, including narwhals (Laidre et al., 2008).

Narwhals have a more northern distribution but are almost as numerous as belugas, many of their aggregations are quite large, and their summer ranges tend to be more remote than those of belugas, which limits their exposure to disturbance to some extent. The main habitat concern for narwhals as the Arctic warms is the loss of sea ice, as narwhals are more directly ice-associated than belugas (see Laidre et al., 2008).

[83] Andreev, A. V., D. I. Berman, P. Yu Gorbunov, N. E. Dokuchaev, V. S. Kononenko, B. A. Korotyaev, A. A. Kochnev, A. V. Krechmar, D. I. Litovka, Yu M. Marusik, L. A. Prozorova, I. A. Chereshnev, F. B. Chernyavsky, O. A. Khruleva. 2008. The red book (endangered species list) of the Chukotka autonomous okrug // Chukotka Dep. Ind. Agricult.;RAS Far Eastern Branch, Northeastern Sci. Center, Inst. Biol. Prob. North. Magadan. - Vol. 1 Animals, p. 235 (avail. at https://www.ipae.uran.ru/sites/default/files/publications/ipae/0876_2008_RedBook_ChukotAO_T1.pdf).

Environmental Changes

Ongoing warming of Arctic waters has already led to major declines in sea ice and changes in the timing and spatial sequence of freeze-up and break-up, which has led to physical changes (distribution, characteristics, and movement of ice—not only as a barrier but also in terms of the protective cover it affords) as well as biotic changes (species presence and abundance) in the habitat (Laidre et al., 2015; CAFF, 2017). Warmer water and reduced sea ice enable boreal species to move into higher latitudes, which means that the species endemic to the Arctic are experiencing changes in prey composition and availability, increased competition for food, greater pressure from predators, and exposure to novel pathogens.

Both monodontid species, but especially narwhals, are closely associated with sea ice, and the movement and migratory patterns of some stocks have already been altered (e.g., Hauser et al., 2017; Stafford et al., 2018). The seasonal changes in ice conditions are less predictable than in the past, putting monodontids at greater risk of ice entrapment in some areas (Laidre and Heide-Jørgensen, 2005). Reductions in sea ice can lead to increased productivity and greater abundance of prey but also to shifts in dominant prey species from benthic to pelagic (Grebmeier et al., 2006). Increased productivity or changes in prey may have a positive effect on monodontids in some regions, at least temporarily. However, they may not be particularly well adapted to make use of newly available prey and they may lose out to competitors that are better adapted to the new habitat structure.

Belugas—Areas Impacted:

- Global concern
- Cook Inlet where there has been a contraction of the range. The range occupied in the last five years is smaller than that occupied in the previous ten years, and the range continues to contract. It is unknown whether this range contraction is due to a smaller population or represents a response to changes in the environment (Shelden et al., 2015).
- Okhotsk, Bering, Chukchi, and Beaufort Seas where climate change has brought considerable changes in sea ice. Changes in behavior, e.g., in the timing of migrations, have been observed that are likely related to changes in sea ice (Hauser et al., 2017).

Narwhals—Areas Impacted:

- All stocks will be affected by changes in the seasonal distribution of ice and the warming of water as narwhals exhibit a seasonal movement pattern that follows the distribution of the sea ice through much of the year (Laidre and Heide-Jørgensen, 2005).
- Narwhals in Baffin Bay feed heavily in winter on Greenland halibut (Laidre et al., 2008, 2015). Reduction in and earlier break-up of sea ice, resulting in a habitat shift away from benthic species such as halibut to pelagic species (Grebmeier et al., 2006), will represent a loss of winter feeding habitat.
- Southern stocks will likely be affected sooner than northern stocks. This may already be evident in the southern parts of East Greenland where narwhals have disappeared (NAAMCO[78]).

Pathogens

Pathogens typically found in warmer regions are beginning to be detected in Arctic and sub-Arctic cetaceans. For example, Bristol Bay belugas have recently (2008 sample, marine mammal sampling began in 1999) tested positive for the presence of *Vibrio parahaemolyticus* (a pathogen commonly associated with gastroenteritis, that proliferates at temperatures above 15°C; Goertz et al., 2013). In Cook Inlet and the Okhotsk Sea, belugas are exposed to pet and livestock pathogens, which is a concern (Norman et al., 2013; Alekseev et al., 2017). Even pathogens that have been present in the Arctic for a considerable time may become virulent under a warmer temperature regime or if lowered immune response is induced by environmental stressors such as increased pollution or toxic algal blooms, causing individuals to become more susceptible to both local and newly arrived pathogens (Burek et al., 2008).

General Industrial Activities

Most industrial activities in the Arctic result in disturbance of some kind to monodontids, e.g., ocean noise, chemical pollution, displacement, habitat modification.

Both Species—Areas Impacted:

- Mainly the southernmost areas; however, as sea ice declines and opens up more areas to development, this will affect northern areas as well.

Shipping/Vessel Traffic

Shipping is increasing in the Arctic (Arctic Council[84]). The Russian Northern Sea Route (NSR) and the Canadian–United States Northwest Passage (NWP) in many cases offer faster travel between North Pacific and North Atlantic ports than is possible following the traditional, more southern routes. Transpolar routes are also under discussion. Major shipping routes are developing from Asia and the U.S. west coast in the south, heading north toward the Bering Strait, and then west through the Russian Arctic and east through the Canadian Arctic—and vice versa. Development of these routes requires construction of support harbors—with associated disturbance caused by construction and icebreaking activities, shipping, and resupply of port communities by ships rather than aircraft.

Shipping has several potential impacts on belugas and narwhals, such as noise disturbance (Finley et al., 1990; Cosens and Dueck, 1993; Lesage et al., 1999; Reeves et al., 2014),

[84]Arctic Council. 2015. Status on implementation of the AMSA 2009 report recommendations (avail. at https://pame.is/images/03_Projects/AMSA/AMSA_Documents/Progress_Reports/AMSArecommendations2015_Web.pdf).

displacement, and exposure to spills of fuel and toxic cargo. Also, ballast water discharged from ships can introduce invasive species or novel pathogens that are capable of surviving in the warmer ocean temperatures in an altered Arctic (Miller and Ruiz, 2014; Ware et al., 2016).

The severity of the impacts of ship traffic and noise on whales will differ according to the type and quality of habitat, on whether the animals are resident or migratory, and on whether the animals are in key habitat areas or in transit between areas. For instance, in open water, the whales can avoid ships, but at the same time ships travel faster than in restricted areas (making more noise) and sound travels farther so the area ensonified will be greater. This could mean that displacement distance is greater than in coastal areas and fjords but that displacement is to a similar habitat of comparable value. In restricted areas where habitat patches are more varied and limited (e.g., inlets, small bays, fjords) there is less room for avoidance without abandoning the preferred habitat and moving to a different habitat. If this results in displacement of the animals, they are moving from preferred habitat, such as foraging, nursing, resting, or socializing areas, to lower-value habitat or habitat that was of similar value but now is supporting more animals. As sea-ice seasons shorten, and remaining sea-ice areas become more restricted, these conflicts will increase. If a shipping lane passes through preferred habitat, the whales are faced with choosing between moving to poorer habitat or remaining in degraded habitat.

Some degree of habituation to noise has apparently occurred in some areas, especially where vessel traffic is regular and somewhat predictable. Commercial ship traffic generally adheres to standard routes, but tour-vessel and recreational boat traffic is less predictable and is expanding both spatially and temporally. This trend is already a major concern in areas such as Cook Inlet and the St. Lawrence Estuary and Gulf and is becoming a major concern in other areas, such as Pond Inlet (Canada), West Greenland, and the White Sea (Russia). Additionally, there is increased military activity in all northern waters, for example a new military base has been established inside the Franz Josef Land National Park (Wezeman[53]).

Spills of fuel and other toxic substances can occur wherever there is ship traffic; however, spills are far more common in harbor and port areas than in open water. Shipping in or near ice-covered waters or during winter weather increases both the risk of spills and the likelihood that the spilled material cannot be contained or cleaned up readily. Cetaceans have little ability to detect and avoid spills or the consequences of a spill. Spilled substances can be inhaled, ingested, or absorbed through the skin, or can enter the food web; the route of exposure depends, in large part, on the chemical nature of the substance (Norman et al., 2015).

Belugas—Areas Impacted:

Belugas are rarely reported as being struck by ships, even in areas with high levels of traffic, likely because they are noise-sensitive and avoid ships. However, such avoidance can itself present a risk because it implies that they are easily displaced from habitat that is critical to them in one way or another.

- Cook Inlet: All shipping into and out of Anchorage, the biggest port in Alaska, goes through beluga habitat. Military vessel traffic is also increasing in the area. The Port of Anchorage is in the passage between the two primary habitat areas for these whales (Shelden et al., 2015).
- Eastern Bering Sea: The southern approach to the Bering Strait passes through or is adjacent to beluga habitat.
- Bering Strait: Both the NSR and NWP pass through the strait. Shipping can therefore affect stocks that use the strait as a migration corridor, particularly in fall when the migration occurs before freeze-up.
- Chukchi Sea: The northern approach to the Bering Strait passes through or is adjacent to spring, summer, and fall habitat of belugas.
- Beaufort Sea and western channels of the Canadian Archipelago: The NWP passes through or adjoins spring, summer, and fall habitat of belugas.
- Western Hudson Bay: All stocks that use this region are affected.
- Baffin Bay: Industrial development and associated shipping are increasing.
- St. Lawrence Estuary and Gulf: The situation is similar to Cook Inlet (see above).
- Northeast Atlantic Arctic: Shipping and marine tour-vessel traffic are increasing in East Greenland and around Svalbard.
- White Sea: Shipping from Arkhangelsk (Severnaya Dvina) through the White Sea to the NSR is increasing with reduced sea ice.
- Russian western and central Arctic (Barents, Kara, and Laptev Seas): Shipping is heavy and increasing. The likely impact is difficult to assess, as very little is known concerning how belugas use these waters, but petroleum development in the Pechora and Kara seas has expanded rapidly with minimal environmental assessment in advance.
- Okhotsk Sea: Shipping of ore and other cargo is increasing and of concern.
- Russian waters generally: Hovercraft shipping, which is very noisy, is developing.

Narwhals—Areas Impacted:

Narwhals are very sensitive to ship noise, more so than belugas, and they will be affected in all parts of their range by increases in shipping.

- Baffin Bay, especially and most immediately in Eclipse Sound and Pond Inlet, but also throughout Lancaster Sound.
- Northern Hudson Bay especially in Hudson Strait, Repulse Bay, and Frozen Strait.

Icebreaking

Icebreaking and the associated ship traffic are increasing throughout the circumpolar Arctic. The loudest sounds are created by cavitation from propellers when ships back up (often to ram ice), but they can also be produced from normal operation of the engines and physically breaking ice. When icebreaking occurs in areas where ice is now thin enough to traverse (e.g., at the beginning of break-up and when leads have formed or refrozen areas are still thin enough for animals to break through), it may lead belugas and narwhals to abandon important habitat (Finley et al., 1990). The impact will depend on the nature and scale of the operation, with large-scale continuous or repeated icebreaking in heavy pack ice being of greatest concern, both as a source of noise disturbance and as the cause of increased risk of ice entrapment. Smaller-scale icebreaking, e.g., for port or harbor maintenance or when the ice is already breaking up but needs to be cleared, is of less concern.

The noise from icebreaking activity may affect belugas' and narwhals' sensory capabilities and make it more difficult for them to find breathing holes, communicate, and use echolocation to find prey. This effect can occur at distances of up to 70 km (Erbe and Farmer, 1998, 2000). Displacement distances could be large and if monodontids are unwilling to pass through an area that is significantly ensonified (Heide-Jørgensen et al., 2013a), icebreaking could effectively block channels even as wide as Lancaster Sound (81 km wide just west of the entrance to Eclipse Sound), a major corridor for several stocks that winter in Baffin Bay, and increase the likelihood of ice entrapment in some areas.

Besides increasing underwater noise, icebreaking changes ice characteristics and movement patterns, which makes the ice less predictable to narwhals and belugas, thereby increasing the risk to them. In some circumstances, icebreaker channels may provide escape routes for entrapped animals. However, belugas have been observed to avoid areas with icebreaking for up to 2 days after the activity has ceased (Cosens and Dueck, 1993), so it may take several days for belugas to make use of an opened channel.

Belugas—Areas Impacted:

Shifts in distribution associated with icebreaking have been observed in Lancaster Sound (Finley et al., 1990; Cosens and Dueck, 1993), although belugas have also shown an ability to habituate under some circumstances (Erbe and Farmer, 1998).

- Hudson Strait: Impacts have been modeled (DFO[70]), but no empirical data have been collected.
- Baffin Bay–Davis Strait: Icebreaking has been proposed to service the Mary River iron mine project in northern Baffin Island (DFO[70]).
- White Sea: Icebreakers pass through the wintering area.

Narwhals—Areas Impacted:

Given their sensitivity to noise, narwhals are likely to be affected by icebreaking, particularly when it occurs in their winter habitat.

- All winter habitat.
- Baffin Bay (including Eclipse Sound and Lancaster Sound; Finley et al., 1990; Cosens and Dueck, 1993).
- Hudson Strait.
- Northeast Greenland: possible icebreaking associated with the Citronen ore project.

Oil and Gas and Other Mining Activities

Seismic Surveys

Oil and gas development generally depends on seismic surveys to explore for deposits and monitor depletion of the deposits over time. Such surveys generate a large amount of high-energy underwater noise, sometimes for months and often in areas that are largely pristine. Seismic operations are planned in advance but take place sporadically in any given area and therefore are not necessarily amenable to habituation by wildlife.

Sound can travel long distances in Arctic waters, and both belugas and narwhals can react to noise from icebreaking activity and ship noise tens of kilometers away, resulting in displacement or disruption of behavior (Finley et al., 1990; Cosens and Dueck, 1993; Erbe and Farmer, 1998, 2000; Miller et al., 2005). If belugas and narwhals abandon areas as a response to disturbance by seismic surveys, this would be equivalent to a loss of habitat. Seismic surveys in fall or winter are problematic because they can delay migration or force the animals into sub-optimal areas, and may also increase the risk of ice entrapment (Heide-Jørgensen et al., 2013a).

The long distances at which monodontids respond to noise creates cross-border problems, as sound generated on one side of a border may impact animals on the other side. Ideally, seismic survey planning should be carried out on a regional, coordinated basis and include consideration of the potential impacts on belugas and narwhals.

Construction and Production

Besides shipping (for supply and export) and seismic surveys, offshore oil and gas development normally requires construction or upgrading of infrastructure (e.g., platforms, drilling rigs, pipelines, sometimes artificial islands). This becomes a constant or nearly constant local source of underwater noise over large areas for years (or even decades) (Lammers et al., 2013). Port development involves dredging and pile-driving as well as support shipping, all of which can disturb monodontids.

Oil Spills

Oil spills in the Arctic are of great concern, especially in ice-covered waters. Arctic conditions make spills difficult or impossible to control and clean up, and the cold temperatures slow the breakdown of spilled oil. Any spill carries the potential for major impacts, especially as the capac-

ity for emergency response remains limited. Oil spills can harm whales as a result of both direct exposure and the contamination of their prey if the prey organisms ingest the oil or are smothered by it. Additionally, efforts to clean up after a spill can themselves cause noise and other forms of disturbance.

Belugas—Areas Impacted:

- All areas where exploration or development occurs.
- Cook Inlet has extensive oil and gas development in a confined area. Besides it being the passageway into and out of Anchorage, there are rigs in the middle of the inlet and pipelines that transport oil and gas to onshore storage facilities where tankers are loaded for shipment. Cook Inlet is an area with significant seismic and volcanic activity and oil and gas infrastructure is always at risk. Earthquakes and active volcanoes create the potential to compound the impacts of infrastructure on belugas. Response plans exist and are being refined and updated, but such plans can, at best, only moderate, not eliminate, the harm that would come from a major spill in Cook Inlet.
- Ungava Bay: Construction of a port is under way near Aupaluk on Hopes Advance Bay at the northwestern corner of Ungava Bay to support shipping in conjunction with an iron ore mine (Oceanic Iron Ore Corp.). However, it is not known if or how this will affect the few remaining Ungava belugas (assuming they have not been extirpated).
- St. Lawrence Estuary: Port development is likely to continue.
- Russian western and central Arctic: The Pechora Sea is of special concern because of major coastal oil and gas development projects in areas of beluga concentrations.
- Western Okhotsk Sea: There is increasing ore development accompanied by construction of terminals and shipping.

Narwhals—Areas Impacted:

Seismic survey activity is now taking place in narwhal habitat. In areas such as Fram Strait, the activity continues 24 h/day during the open-water season, which can mean that narwhals are delayed or prevented from moving away from their coastal summering areas during late summer or early fall, and they may be forced to remain in areas with fast ice, increasing the risk of ice entrapment and delaying their chance to feed in their winter habitat. Seismic surveys should be avoided at the start of or during migration periods.

- All areas with seismic surveys will be affected.
- Eclipse Sound: Port development in Milne Inlet for the Mary River iron mine is ongoing.
- Melville Bay: Seismic surveys displaced narwhals into coastal areas and fjords during the survey period (Hansen et al.[72]).
- East Baffin Island: Seismic surveys.
- East Greenland/Fram Strait: More exploration and eventual development is planned.
- Russian Arctic: Seismic surveys and planned oil and gas development.

Hydroelectric Development

Hydroelectric development is of particular concern in Canada, especially with dam construction in rivers flowing into Hudson Bay and James Bay (damming of rivers along the north shore of the Estuary and Gulf of St. Lawrence was essentially completed by around 1970). These dams change the hydrological characteristics of estuaries and coastal waters, potentially affecting belugas because they associate with estuaries. The altered flow regime downstream of dams can influence seasonal temperature and salinity in estuaries and make them less suitable for belugas, and change distribution and abundance of prey species. Dams interrupt the flow of sand and silt in rivers, which over time can result in changes to the substrate and distribution of shallow areas that belugas occupy. Freshwater releases in late fall or winter can affect the timing of freeze-up, making the sea ice less labile and thereby possibly increasing the risk of ice entrapment.

Belugas—Areas Impacted:

- St. Lawrence Estuary.
- Eastern Hudson Bay and James Bay.

Interactions with Fisheries

Fisheries impact marine mammals through competition for resources, injury and entanglement in gear, and loss or degradation of habitat. Injury and entanglement is reported on occasion but does not appear to be a major problem for belugas or narwhals. However, in many areas there is little or no monitoring which means that incidents are unlikely to be reported and animals entangled in lost gear are unlikely to be found (Treble and Stewart[85]). Also, in some areas subsistence hunters use large-mesh nets to harvest whales (e.g., western Hudson Bay and eastern Bering Sea) and incidentally caught whales are often reported as catch rather than as bycatch (e.g., in Greenland and Alaska).

Competition for resources, including preferred prey items, is the main issue with regard to fishery interactions. Narwhals have a narrow dietary niche and increased commercial fishing for their dominant prey, Greenland halibut, is of concern, particularly in Baffin Bay. Halibut have traditionally been harvested in the fjords of West Greenland using long-lines and gillnets. An additional offshore commercial fishery developed in the 1960's in Davis Strait. This fishery continues to expand to the deep waters of central Baffin Bay where narwhals feed during winter.

A number of stocks of belugas de-

[85]Treble, M. A., and R. E. A. Stewart. 2009. Impacts and risks associated with a Greenland halibut (*Reinhardtius hippoglossoides*) gillnet fishery in inshore areas of NAFO Subarea 0. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/032. vi + 18 p. (avail. at https://waves-vagues.dfo-mpo.gc.ca/Library/340821.pdf).

pend on anadromous fish runs, particularly salmonid species, smelt, and whitefish which support commercial, sport, or subsistence fisheries. These fisheries often intercept returning adult fish offshore from the shallow estuarine areas where belugas feed. Also, in some areas fishing is carried out with shallow set nets in areas where belugas also feed, and these nets remove prey and disrupt both the behavior of prey and the pursuit of prey by belugas. Finally, where fisheries have been scaled back due to overfishing, the spawning stock is reduced and outrunning juvenile fish that belugas also feed on are reduced.

Destruction or degradation of habitat may be caused by trawl fisheries. An example is trawling through the corals inhabited by the halibut in Baffin Bay (Yesson et al., 2016). As the fisheries expand northward, more and more habitat is likely to be degraded or destroyed.

Belugas—Areas Impacted

Belugas can swim backward, and fishing nets are probably detectable by their echolocation although as noted above, some hunting communities use entanglement to catch belugas so they are not always able to avoid or escape from nets. Entanglement in fishing gear does not occur as frequently as might be expected given the intensity of fishing, particularly for salmon, in beluga feeding areas. In the St. Lawrence Estuary, for example, there is significant fishing activity in beluga habitat, yet very little beluga bycatch is reported (Bailey and Zinger[86]; Lair[87]), suggesting that the whales usually avoid entanglement. Entanglements are reported annually in the Okhotsk Sea, but reports are infrequent.

In areas where belugas forage in estuaries, they tend to feed in the shallow upper parts of estuaries, whereas fishing tends to be concentrated in the mouths of the estuaries, limiting direct interactions, but still creating a situation that could limit the amount of prey available to the whales. This is of particular concern for belugas in the Pacific Arctic and for populations that have a fairly narrow summer dietary niche focused on anadromous fish species.

Better information is needed on the diet of many stocks of belugas to assess the possibility of competition with fisheries more rigorously.

- Sakhalin-Amur: The salmon fishery may be reducing the carrying capacity for belugas (Shpak et al., 2019).
- Anadyr: Competition from salmon fishery (Shpak et al., 2019).
- Cook Inlet: Competition from salmon (species) and eulachon, *Thaleichthys pacificus*, fisheries (Norman et al., 2015, 2019).

Narwhals—Areas Impacted

Competition occurs with several fisheries but notably the Greenland halibut fisheries, which are expanding northward because of ice recession.

- Baffin Bay, Davis Strait: Competition with Greenland halibut and shrimp fisheries probably affects all stocks wintering in these areas (Laidre et al., 2008, 2015).
- Hudson Strait: There is likely competition with Greenland halibut and shrimp fisheries.
- East Greenland: There is likely competition with Greenland halibut fisheries.
- Svalbard: There is likely competition with fisheries for polar and Arctic cod, *Arctogadus glacialis* and *Boreogadus saida*, respectively), Greenland halibut, and possibly shrimp.

Organic Contaminants and Heavy Metals

In some areas pollution, especially by heavy metals, polychlorinated biphenyls (PCB's), plastics, and microplastics, is a concern for belugas and narwhals. Some contaminants (particularly organic contaminants) are transported from lower latitudes (via the atmosphere or ocean currents) and some also originate in certain areas from local run-off, sewage, and mine outfalls. Studies have shown pollution to be an acute problem for belugas in some areas; however, studies on narwhals are limited. Extensive studies of the belugas in the St. Lawrence Estuary (Béland et al., 1993; Martineau et al., 1994; Martineau, 2010) have indicated that elevated rates of cancers, and of bacterial, viral, and parasitic infections, are correlated with high levels of pollutants (Martineau et al., 1988, 1999, 2002; De Guise et al., 1994, 1995; Lair et al., 2016). Contaminant studies have been conducted on belugas in Alaska (Becker et al., 2000; Norman et al., 2015), the Canadian Arctic (Loseto et al., 2015), Svalbard (Wolkers et al., 2006), and the western Okhotsk Sea (Glazov et al.[13]). Svalbard belugas have relatively high levels of several contaminants (Wolkers et al., 2006). A pilot study in the western Okhotsk Sea showed that belugas summering in the estuaries of large rivers are relatively heavily contaminated with pesticides (Glazov et al.[13]). More information is needed on the impacts of plastics and microplastics on the health of both monodontids.

Belugas—Areas Impacted

- Cook Inlet: There is runoff from roadways, airports, agriculture, and military facilities as well as sewage outfalls from Anchorage and other municipalities and private septic systems (Norman et al., 2015).
- Canadian Arctic waters: This was a particular problem in the eastern Beaufort Sea, where mercury concentrations in beluga tissues were increasing through the 1990's but

[86]Bailey, R., and N. Zinger. 1995. St. Lawrence beluga recovery plan. World Wildlife Fund, Toronto, and Fish. Oceans Can., Mont-Joli (Québec), 73 p.

[87]Lair S. 2007. Necropsy program: health monitoring of the St. Lawrence Estuary beluga population using post-mortem examination of stranded carcasses. *In* Proceedings of the workshop on the St. Lawrence Estuary beluga—review of carcass program, November 14-17, 2005, Mont Joli. L. Measures (Ed.). Dep. Fish. Oceans, Can. Sci. Advis. Secretariat, Proc. Ser. 2007/005. p. 11–14 (avail. at http://www.dfompo.gc.ca/csas/Csas/Proceedings/2007/PRO2007_005_E.pdf).

levels now seem to be declining slightly (Loseto et al., 2015).

- St. Lawrence Estuary: Currently, runoff from roadways, airports, agriculture, and industrial and port facilities drains into the St. Lawrence watershed, and historically considerable industrial pollution entered the tributaries of the Great Lakes and St. Lawrence River. As a result, St. Lawrence belugas have very high loads of organochlorine compounds and heavy metals in their tissues (Béland et al., 1993; Martineau et al., 1994; Martineau, 2010).
- Svalbard: Levels of various pollutants in Svalbard belugas are very high and for many compounds higher than what is found in polar bears in the area (Andersen et al., 2001, 2006; Wolkers et al., 2004, 2006; Villanger et al., 2011).
- White Sea: Industrial pollution, organochlorine compounds, and heavy metal contaminants (Glazov et al.[54])
- Sakhalin Bay–Amur River: The Amur River carries industrial pollution, mine waste, agricultural runoff, and sewage (Shpak et al., 2019)
- Udskaya Bay: Agricultural runoff.

Narwhals—Area Impacted

- Studies on contaminants in narwhals are needed in all areas but particularly in areas such as Svalbard where belugas are known to have high levels of contaminants.

Cumulative Impacts

Individual stressors might not have significant impacts on individual animals or populations, but stressors rarely occur in isolation. The repetitive and combined pressure of multiple stressors is not always simply additive—the effects can also be synergistic (see examples in Norman et al., 2015). Cumulative effects can lead to mortality and morbidity of individuals, whereas the stressors when considered separately may not. Many stressors have similar effects such as reduced foraging success, reproductive capacity, and immune function, and thus must be considered together to understand the net impact on the population.

Cumulative impacts are a global concern for both species, but most of the focus on assessing and attempting to mitigate such impacts has been on stocks that are already believed to be at greatest risk because of low abundance, declines in abundance, and known exposure to acute stressors. It is not clear how belugas and narwhals will respond to the cumulative, rapid changes now occurring, but there is some evidence that they have some flexibility (belugas perhaps more than narwhals). Therefore, some stocks might manage to deal with changes while others do not (Kovacs and Lydersen, 2008; Laidre et al., 2008; Heide-Jørgensen et al., 2010a; Kovacs et al., 2011).

Belugas—Areas Impacted

- Cook Inlet: Pollution, competition from fisheries, anthropogenic noise, shipping, and construction (Norman et al., 2015).
- St. Lawrence Estuary: St. Lawrence belugas have very high tissue loads of organochlorine compounds and heavy metals (Béland et al., 1993; Martineau et al., 1994; Martineau, 2010) which are likely to interact with competition from fisheries, anthropogenic noise, shipping, construction, and whale-centered tourism.
- White Sea: Industrial pollution, organochlorine compounds and heavy metal contaminants, competition with fisheries, anthropogenic noise, shipping (Glazov et al.[54]).
- Sakhalin Bay–Amur River: Competition with fisheries, anthropogenic noise, shipping, construction (Shpak et al., 2019)

Narwhals—Areas Impacted

- Baffin Bay, Davis Strait: Competition with Greenland halibut and shrimp fisheries (Laidre et al., 2008, 2015); icebreaking and shipping interfere with migration and access to winter habitat.
- Hudson Strait: Likely competition with Greenland halibut and shrimp fisheries, effects of icebreaking and shipping.

Impact Assessment of Different Threats

Ideally, meaningful quantitative analyses of the cumulative impacts of multiple threats should be part of impact assessment, but this is usually not even attempted. Authorization requests from mining interests and oil and gas operators, for example, almost invariably focus on the impacts of their individual projects or activities in isolation, and do not give serious consideration to the cumulative impacts of environmental changes by other projects.

The methodology for quantitative assessment of cumulative impacts is not well developed for any Arctic cetacean species. Therefore, additional scientific effort is needed to develop and make available assessment methods that are understandable, quantitative, meaningful, and repeatable.

In all areas, the impact assessment and approval processes and the response plans for development activities are of concern. The precautionary approach is often used in harvest management (as it should be), but companies planning development activities are generally not held to the same standard of precaution. For example, the beluga and narwhal harvests in Canada and Greenland are closely monitored and managed, yet development projects are rarely halted or even significantly modified when they are known to have, or are likely to have, significant impacts on monodontid stocks.

Recommendations for Monodontid Research and Cooperation

Abundance Estimates

There are several areas where no dedicated surveys of monodontid stocks have been conducted, the available data are outdated, or there is a single estimate and therefore it is not possible to assess trend. Reliable information on abundance is critical to assessment of status. New or improved technology (satellite imagery, drones,

genetic mark-recapture, etc.) is available that could be used as an alternative to aerial surveys for collecting data less expensively and with greater safety to humans. However, it is important that new methods be comparable to previous methods so that trend assessment is feasible. Stocks with no abundance estimate or with abundance estimates that were older than 5 years at the time of the GROM workshop are listed below, and these should be assigned a high priority.

Beluga stocks with no survey data:

- Svalbard (planned 2018),
- Barents-Kara-Laptev Seas, and
- Anadyr

Beluga stocks with most recent survey older than 5 years:

- Eastern Beaufort Sea (1992),
- High Arctic-Baffin Bay (1996),
- Eastern Bering Sea (2000; surveyed June 2017, see Update under stock review),
- Sakhalin Bay–Amur (2010),
- Ulbansky (2010),
- Tugursky (2010),
- Udskaya (2010), and
- Shelikov (2010).

Narwhal stocks with no survey data:

- Northeast Greenland (partial survey after the workshop in 2017 and in 2018; results in stock review above), and
- Svalbard-Russian Arctic (partial survey in Norwegian waters 2015).

Narwhal stocks with most recent survey older than 5 years:

- Inglefield Bredning (2007), and
- Northern Hudson Bay (2011; surveyed 2018, results unavailable).

Stock Identity

The ability to assign individual whales to the correct stock is a high priority. It is especially important for narwhals in areas where they are hunted, but it is important for numerous beluga stocks whether they are hunted or not, including Svalbard, Barents-Kara-Laptev Seas, eastern Hudson Bay, White Sea, and western Hudson Bay. Collection of tissue samples from areas where narwhals and belugas are harvested is important, but it will also be important to obtain samples (e.g., via remote biopsy, opportunistic access to stranded or bycaught individuals) from across the range of both species.

Movements and Distribution: Satellite Tracking

Shifts in the movements and distribution of belugas and narwhals have been observed over the last 20 years, and there is a need for additional satellite-linked tagging and tracking. This should be done in areas where no data are available on movements and also in areas like James Bay where previous tagging was limited. Information obtained from satellite tracking can be used in many ways, such as investigating the effects of industrial activities or shipping on whale movements and providing a basis for designing aerial surveys for abundance estimation.

Telemetry data can also be used to identify important areas and times to conduct surveys, determine where and when different stocks overlap spatially, and help prevent overestimation of abundance due to "double counting." Importantly, dive data from satellite tags are used in developing correction factors to account for availability bias in data from aerial surveys; these factors have a large influence on abundance estimates and are best developed from tags deployed during the survey period and in the surveyed area. Movement data from satellite tracking also provide a valuable supplement to genetic analyses for defining stocks. This is particularly important for narwhals as movement data are used to assign takes during fall, winter, and spring hunts to the appropriate summer aggregations.

Satellite tagging is particularly needed in the following areas:

Belugas

- James Bay (especially the west coast),
- Eastern Hudson Bay,
- Belcher Islands,
- Cumberland Sound,
- Okhotsk Sea, and
- Russian Arctic.

Narwhals

- East Baffin Island,
- Jones Sound and Smith Sound, and
- East Greenland, Svalbard, Franz Josef Land, northern Russia.

Responses to Disturbance

Considering the increase in human activities in the Arctic, there is a need for controlled studies on the behavioral and physiological responses of monodontids to disturbance, particularly in relation to ship traffic, icebreaking, oil and gas activities, and human-generated noise generally. Studies should include, for example, investigating the movements, heart rate, stress hormone levels, and sleep/rest rhythm of tagged animals in the presence and in the absence of potentially disturbing stimuli. Baffin Bay was identified as a particularly important area for such studies although it was recognized that findings from robust studies of monodontids regardless of the study site could have considerable value.

Although controlled experiments with wild monodontids concerning their responses to various types of vessel traffic, seismic surveys, and icebreaking activities are lacking, the observational evidence that is available suggests that both species are very sensitive to anthropogenic sounds and that those sounds can disrupt normal behavior, cause the animals to move away from preferred habitat, and increase the risk of ice entrapment in some areas (NAMMCO[29]). Therefore, it is recommended that seismic surveys and icebreaking activities be avoided, at least in areas and during times when the whales are likely to be most vulnerable (e.g., when they are migrating toward wintering areas and while they are in wintering areas where there is limited access to open water; breeding or calving areas and seasons; etc).

Health Assessment

Health assessment studies can provide useful information to managers on the status of beluga and narwhal

populations and basic biological data for researchers studying the impacts of threats. Such studies can also provide valuable information on the benefits and risks of consuming the whales' skin, meat, and organs to the human communities that rely on these animals for food. Although no health assessment projects are currently under way on narwhals, several such projects on belugas are ongoing in Alaska, notably in Bristol Bay (Norman et al., 2012; Castellote et al., 2014), Point Lay (eastern Chukchi), and Cook Inlet, in the Inuvialuit region of Canada (Loseto et al., 2015), and in the Russian Far East, specifically on the Sakhalin-Amur stock.

Local Knowledge

Knowledge held by local people, subsistence hunters in particular, is an important source of information on monodontids, especially in locations where little scientific field research on belugas and narwhals has been or is being carried out. Such knowledge has been used to inform stock delineation and will continue to do so, and it can also provide valuable information on population trends, impacts of disturbance, and environmental changes, both short-term and long-term and both natural and human-caused. In Canada, the Species at Risk Act recognizes Aboriginal Traditional Knowledge (ATK) as central to the process of assessing risks and assigning species and populations to different levels of concern. ATK and Indigenous Peoples also play an important role in the development and implementation of protection and recovery measures.

Cumulative Impacts and Management Advice

The importance of integrating consideration of cumulative impacts into management advice is widely recognized, but such integration is rarely achieved. In the case of monodontids, management advice has historically focused on hunting, although it is increasingly recognized that these whales face multiple threats and that various threats in addition to hunting must be considered and addressed. Restrictions on hunting are often necessary to enable populations to recover and to prevent them from decreasing, but other human activities that are known or suspected to have serious impacts on monodontid populations are rarely subject to meaningful restrictions. This situation needs to change. A precautionary approach should be applied equally to the management of harvesting, industrial and commercial activities, tourism, and scientific exploration.

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Distribution, Abundance, Harvest, and Status of Western Alaska Beluga Whale, *Delphinapterus leucas*, Stocks

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Introduction

Beluga whales, *Delphinapterus leucas* (also called white whales), are a conspicuous and important component of the marine mammal fauna of western Alaska. Early reports indicated regular spring, summer, and fall occurrences of belugas in the Bering Sea in Bristol Bay (Brooks et al.[1]; Lensink[2]), Norton Sound and the Yukon Delta (Nelson, 1887; Zagoskin, 1967), and in the Chukchi Sea in Kotzebue Sound and along lagoons near Point Lay (Nelson, 1887; Foote and Williamson, 1966; Childs[3]). Traditional knowledge of Alaska Natives indicated that these occurrences represented long established migration routes and summer concentration areas, and that belugas were an important subsistence resource harvested at many coastal villages (Huntington et al., 1999; Neakok et al.[4]; Chythlook and Coiley[5]).

Research on belugas in Alaska initially focused on competition with commercial fisheries but later included potential impacts of proposed oil and gas leasing. Belugas in Bristol Bay were the subject of early scientific attention mostly because the largest commercial sockeye salmon, *Oncorhynchus nerka*, fishery in the world occurs there (Jones et al.[6]) and

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ABSTRACT—The Alaska Beluga Whale Committee co-manages three western Alaska beluga whale Delphinapterus leucas, *stocks with the National Marine Fisheries Service, NOAA, and has conducted studies on stock identity, distribution, abundance, and subsistence harvests. Studies of mitochondrial DNA revealed substantial differentiation among belugas that use summering areas in Bristol Bay, the eastern Bering Sea, and the eastern Chukchi Sea, and there is little overlap in their seasonal distributions. The Bristol Bay stock summers in bays in inner Bristol Bay and winters in outer Bristol Bay. Abundance estimates from aerial surveys increased by more than 4% per year during 1994–2005. Survey counts in 2016 were similar to 2004–2005 indicating that the population may now be stable. Survey results and a genetics mark-recapture study indicate a population of approximately 2,000 whales. The average annual Alaska Native subsistence harvest over the past decade (23) is below the calculated potential biological removal (PBR; 39-43). The eastern Bering Sea beluga stock concentrates in summer off the Yukon River Delta and in Norton Sound and in winter moves offshore in the eastern Bering Sea. Abundance has been estimated at approximately 9,242 based on aerial survey data collected in 2017. The average annual subsistence harvest, plus the estimated number of struck and lost belugas, is 215 and exceeds the PBR calculated from this abundance estimate (201), but the abundance estimate is thought to be biased low and local and traditional knowledge does not indicate any decrease in abundance or availability. The eastern Chukchi Sea stock is migratory, wintering in the northern Bering Sea, moving north through the eastern Chukchi Sea in spring, and summering in the Beaufort Sea and Arctic Ocean. It is large, estimated at approximately 20,000 animals based on 2012 aerial surveys. The average annual subsistence harvest (57) is well below PBR (293). Few significant threats to persistence of western Alaska beluga stocks have been identified, although climate warming and declines in sea ice and industrial activities related to resource development and increases in commercial shipping are of concern and could pose challenges in the future. Continued monitoring of population size and trend, subsistence harvest, and health of western Alaska belugas is warranted.*

salmon stocks were depleted. Studies began in Bristol Bay in the 1950's because of concern that belugas were consuming enough salmon smolt to limit salmon populations (Brooks et al.[1]; Lensink[2]) and there was pressure by commercial fisheries to reduce beluga predation on salmon (Fish and Vania, 1971).

Research throughout western Alaska began in 1977 to assess potential impacts of oil and gas exploration and development in the Bering, Chukchi, and Beaufort seas (Burns and Seaman[7]). Compilations of observational data confirmed the widespread distribution and common occurrence of belugas in western Alaska (Seaman et al.[8]). When all available sightings were plotted, a non-uniform distribution of belugas in coastal waters during the summer was evident and suggestive of population subdivisions (Frost and Lowry, 1990). This summer distribution pattern formed the basis for provisional stock designations recognizing that genetic studies would be required to confirm underlying patterns of relatedness among the seasonal groupings (O'Corry-Crowe and Lowry, 1997).

The Alaska Beluga Whale Committee (ABWC) was formed in 1988 to conserve beluga whales and manage beluga subsistence hunting in western Alaska in cooperation with NOAA's National Marine Fisheries Service (NMFS) (Adams et al., 1993; Fernandez-Gimenez et al., 2006; ABWC[9]). When the ABWC was formed, there was no consistently funded research or management program for belugas in Alaska. With its formation, the ABWC brought together representatives from beluga hunting communities in Alaska; federal, state, tribal, and local governments; and beluga researchers to develop and implement a program to provide the data needed for sound beluga management. Goals of the ABWC were to identify management stocks in western Alaska, estimate abundance and trends of those stocks, and monitor the number of belugas harvested from those stocks for subsistence by Alaska Natives. In furtherance of these goals and with funding from NMFS and other cooperators, the ABWC has conducted a total of 23 multi-day aerial surveys of belugas in three areas, Bristol Bay (N = 7), Norton Sound/Yukon Delta (N = 7), and the eastern Chucki Sea (N = 9) since 1990. The ABWC began satellite tracking studies of beluga movements and habitat use in 1996, and has facilitated and collaborated in beluga tracking studies, including the training of hunters to attach transmitters, in Bristol Bay (N = 69), Norton Sound (N = 7), and the eastern Chukchi Sea (N = 30). In 1989, the ABWC initiated a pioneering genetics study of beluga stock identity and by 2017 had facilitated the collection of more than 2,000 beluga skin samples. It supported a genetics-based mark-recapture study to estimate beluga abundance in Bristol Bay and to validate aerial survey estimates. The ABWC has collected subsistence harvest data during 1987–2017 from more than fifty Alaska communities where beluga hunting occurs. The ABWC stands as a model of what can be achieved when scientists, Alaska Native hunters, and managing agencies work together.

The goal of this manuscript is to update what is known about the stock identity, distribution, abundance, subsistence harvest, and fisheries bycatch of the three stocks of beluga whales that are co-managed by the ABWC in western Alaska (i.e., Bristol Bay, eastern Bering Sea, and eastern Chukchi Sea stocks). Using recent abundance and harvest information, we calculate the Potential Biological Removal (PBR) (Wade and Angliss, 1997) and comment on sustainability of current anthropogenic removals. To facilitate the use of this information for NOAA Stock Assessment Reports (SAR's), we follow the format found in those reports.

Identity of Management Stocks

To understand the relationship of belugas summering in different regions of western Alaska, the ABWC sponsored genetic studies. A total of 1,212 beluga skin samples were collected from this region, many by Alaska Native beluga hunters. Differences in mitochondrial DNA (mtDNA; Fig. 1) from different regions led to the identification of four genetically distinct stocks (Fig. 2) in the eastern Bering, Chukchi, and Beaufort seas: 1) Bristol Bay (BB), 2) eastern Bering Sea (EBS), 3) eastern Chukchi Sea (ECS), and 4) Beaufort Sea (Muto et al., 2018). All of these stocks are genetically distinct from the stock in Cook Inlet. These genetic differences likely reflected long-established patterns of female-mediated philopatry and group isolation (O'Corry-Crowe et al., 1997, 2002, 2018; Brown-Gladden et al., 1997, 1999; Meschersky et al., 2008, 2013). Data from aerial surveys and satellite-linked depth recorders (SDR's) attached to whales have shown that each stock has distinct seasonal distribution patterns (see Distribution and Movements below and Fig. 2). The three stocks, BB, EBS, and ECS, that have summer concentration areas in western Alaska are the subject of this review. We do not consider Gulf of Anadyr belugas, because they summer in eastern Russia and are not known to range into Alaska waters (Citta et al., 2016; Litovka et al.[10]; Fig.

Rep. 13-20, Div. Commer. Fish., Anchorage, AK (avail. at www.adfg.alaska.gov/FedAidPDFs/FMR13-20.pdf).

[7]Burns, J. J., and G. A. Seaman. 1988. Investigations of belukha whales in coastal waters of western and northern Alaska. II. Biology and ecology. U.S. Dep. Commer., Outer Continental Shelf Environ. Assess. Prog. Fin. Rep. 56: 221-357 (avail. at https://www.boem.gov/ESPIS/0/81.pdf).

[8]Seaman, G. A., K. J. Frost, and L. F. Lowry. 1988. Investigations of belukha whales in coastal waters of western and northern Alaska. Part I. Distribution and abundance. U.S. Dep. Commer., Outer Continental Shelf Environ. Assess. Prog. Fin. Rep. 56:153-220 (avail. at https://www.boem.gov/ESPIS/0/82.pdf).

[9]Alaska Beluga Whale Committee (ABWC). 1999. Agreement between the National Marine Fisheries Service and the Alaska Beluga Whale Committee for co-management of the western Alaska beluga whale population. Avail. from North Slope Borough, Dep. Wildl. Manage., Box 69, Barrow, AK 99723, 8 p.

[10]Litovka, D. I., R. C. Hobbs, K. L. Laidre, G. M. O'Corry-Crowe, J. R. Orr, P. R. Richard, R. S. Suydam, and A. A. Kochnev. 2002. Research of belugas *Delphinapterus leucas* in Anadyr

2, 3). Beaufort Sea belugas winter in the Bering Sea (Citta et al., 2016; Fig. 3), are harvested at some locations in Alaska during spring migration (see Point Hope in Fig. 1), and spend summers near and offshore of the Mackenzie estuary, Canada (Hauser et al., 2014; Fig. 2). We do not review the Beaufort Sea stock in this paper because research has been conducted primarily by Canadian researchers and the majority of removals occur in Canada.

Belugas found in Kotzebue Sound deserve special mention. Studies conducted in the 1970's and early 1980's reported belugas entering Kotzebue Sound in mid- to late-June every year, during or shortly following ice breakup (Frost and Lowry, 1990; Seaman et al.[8]). Traditional knowledge confirmed this was a long-established summer concentration area (Huntington et al., 1999). The number of whales returning to Kotzebue Sound declined substantially after 1983 and has not recovered; however, belugas have entered the Sound intermittently in summer in some subsequent years (Frost and Lowry, 1990; Seaman et al.[11]). MtDNA characteristics of belugas harvested before the decline showed that those taken by Kotzebue Sound hunters in the early 1980's differed from the other western Alaska stocks (O'Corry-Crowe et al., 2016, 2018). O'Corry-Crowe et al. (2018) also determined that belugas recently harvested in Kotzebue Sound, at least in years with adequate sample sizes, were either from the Beaufort Sea stock or from a group closely related to that stock. Why the group of belugas using Kotzebue Sound declined after 1983, the status of that group of belugas prior to 1983, and the relationships of belugas harvested since 1983 to other stocks remain unclear. These are current topics of research, and because of the uncertainty described above we do not consider Kotzebue Sound belugas further in this paper.

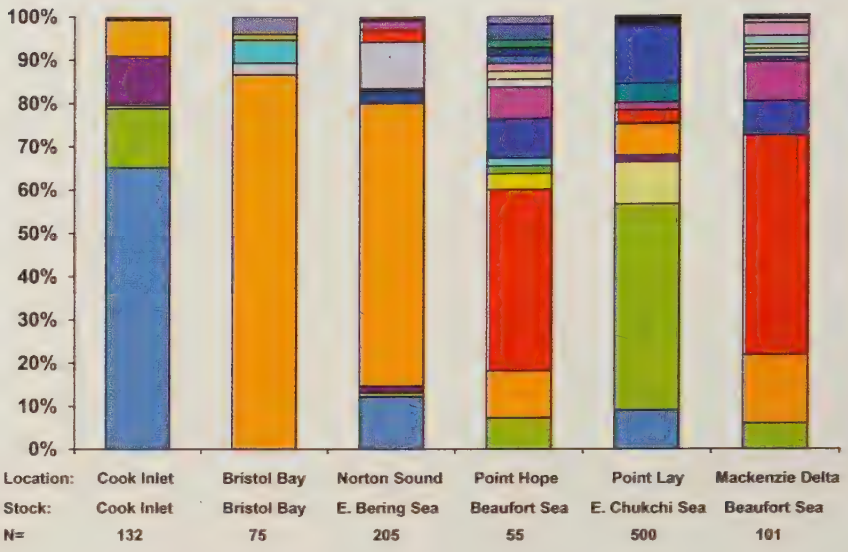

Figure 1.—Frequency distribution of the distinct mtDNA lineages found in the five major geographic regions used by summering beluga whales in Alaskan and northwestern Canadian waters: Cook Inlet, Bristol Bay, eastern Bering Sea, eastern Chukchi Sea, and the Beaufort Sea, as well as one spring migration location, Point Hope, Alaska (adapted from O'Corry-Crowe et al., 1997, 2002, 2018). Each mtDNA lineage, or haplotype, is denoted by a different color. The location of the summer aggregation, stock identity, and sample size are given at the bottom of the figure.

Distribution and Movements

Bristol Bay

Telemetry studies using SDR's indicate that BB belugas are typically found in Nushagak and Kvichak bays and associated river mouths and tributaries during the summer and range more widely in the northeast region of Bristol Bay in the winter (Citta et al., 2016, 2017). In spring and summer (Fig. 4a, b), their distribution is largely restricted to Nushagak and Kvichak bays (Frost et al., 1985; Lowry et al., 2008; Citta et al., 2016; Frost et al.[12]), where belugas are known to feed on a variety of prey, including salmonids, other fishes, and invertebrates (Quakenbush et al., 2015; Brooks et al.[1]; Lowry et al.[13]). After the salmon runs end in late summer, belugas widen their distribution, but remain mostly within Nushagak and Kvichak bays (Fig. 4c; Citta et al., 2016). In winter, BB belugas range into outer Bristol Bay as far as Cape Newenham (Fig. 4d; Citta et al., 2016) and frequent the inner bays less often, perhaps because the bays are covered in ice and pose a risk of entrapment or because few prey are available there. In winter, BB belugas are known to spatially overlap with belugas from the EBS stock but they have not overlapped in time, although sample size is small (Fig. 3). Belugas in both stocks were tracked in 2013,

Gulf (Chukotka) using satellite telemetry. Marine Mammals of the Holarctic. Abstracts of the conference presentations. Moscow, p. 161–163 (avail. at http://marmam.ru/upload/conf-documents/mmc2002_full.pdf).

[11]Seaman G., E. Barger, and R. Lee. 2015. Buckland Beluga Whale Traditional Knowledge Project. Final Rep. Avail. from North Slope Borough, Dep. Wildl. Manage., Box 69, Barrow, AK 99723.

[12]Frost, K. J., L. F. Lowry, and R. R. Nelson. 1984. Belukha whale studies in Bristol Bay, Alaska. *In* B. R. Melteff (Editor), Proceedings of the workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea, p. 187–200. Alaska Sea Grant Report 84-1, Univ. Alaska, Fairbanks. Alaska Sea Grant. P.O. Box 755040, 201 Elvey Building, Fairbanks, AK 99775-5040.

[13]Lowry, L. F., K. J. Frost, and G. A. Seaman. 1988. Investigations of belukha whales in coastal waters of western and northern Alaska. Part III. Food habits. U.S. Dep. Commer., Outer Continental Shelf Enviromental Assessment Program Fin. Rep. 56:359–391 (avail. at https://www.boem.gov/ESPIS/0/80.pdf).

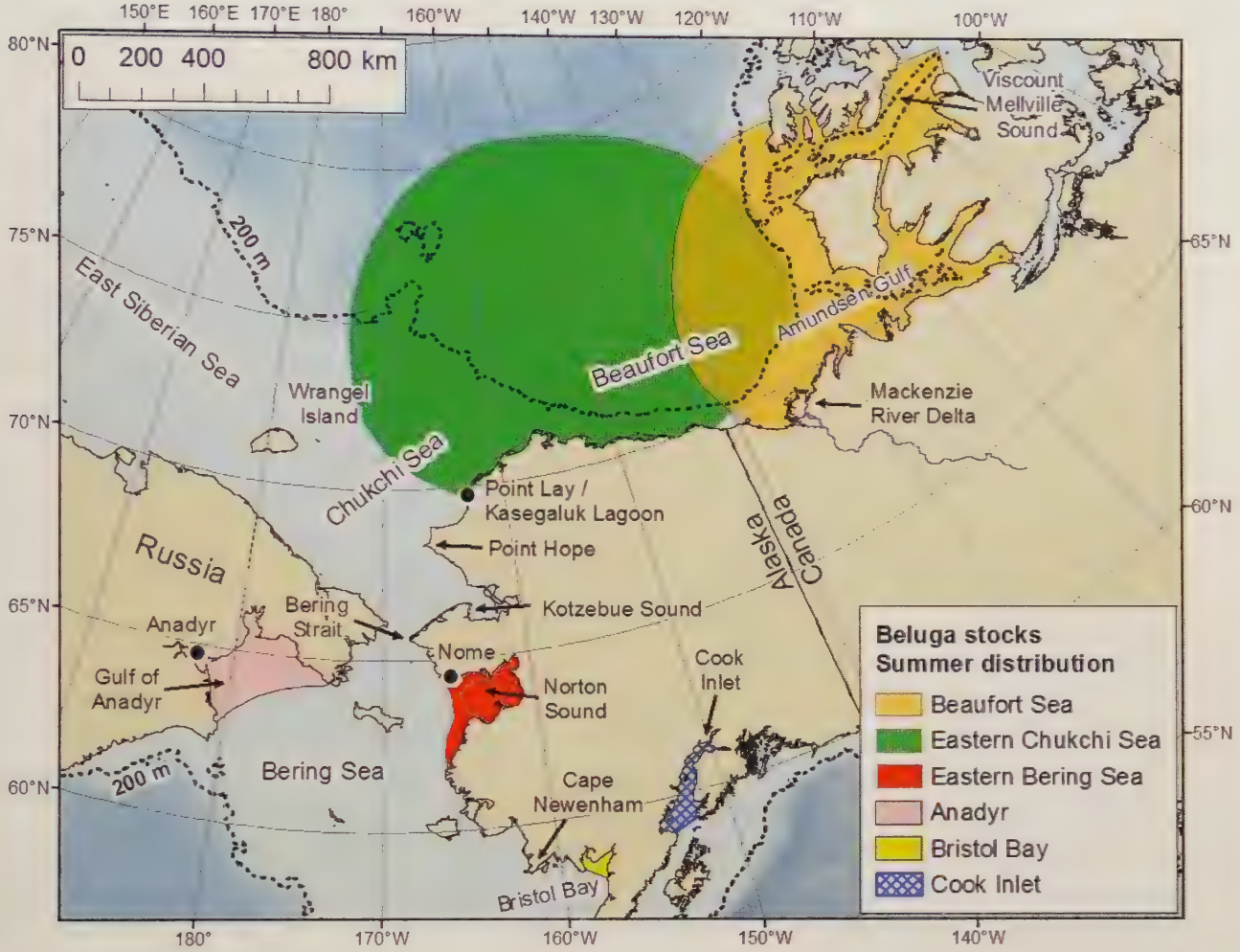

Figure 2.—The summer distribution of known beluga whale stocks in the Bering, Chukchi, and Beaufort seas. Figure modified from Citta et al. (2017).

and although one EBS beluga moved southeastward into the winter range of BB belugas in January, BB belugas had moved into the inner bay, therefore there is no evidence that the two stocks were in the same place at the same time (Citta et al., 2017).

Eastern Bering Sea

Although there were few winter sightings, Frost and Lowry (1990) reported belugas in the Norton Sound region in all seasons. ECS and Beaufort Sea belugas may migrate through the western part of this region in spring and autumn when moving between summering grounds in the Chukchi and Beaufort seas and wintering grounds in the Bering Sea, but only the EBS stock occupies nearshore waters in the northeastern Bering Sea in summer (Fig. 2).

Aerial surveys for belugas in the Yukon Delta/Norton Sound region were begun by the ABWC in 1992. Most surveys were flown in June when belugas were concentrated off the mouths of the Yukon River and in southern Norton Sound (Lowry et al., 2017a; Lowry et al.[14]). High densities were observed along the 5 m isobath in silt-laden Yukon River water (Fig. 5) where belugas were most likely feeding on Pacific salmon, *Onchorhynchus* spp. Belugas are known to occur hundreds of kilometers up the Yukon River on occasion, presumably following salmon. In spring and fall, belugas are seen along the coast at many locations in the Yukon Delta/Norton Sound region (Nelson, 1887; Frost and Lowry, 1990).

SDR's were attached to two belugas in northern Norton Sound near Nome in the autumn of 2012 (Citta et al., 2017). Those whales remained in Norton Sound in October and early November, then as sea ice cover advanced they moved out of the Sound and southward, but remained in the eastern Bering Sea

[14]Lowry, L. F., D. P. DeMaster, and K. J. Frost. 1999. Alaska Beluga Whale Committee surveys of beluga whales in the eastern Bering Sea, 1992–1995. Paper SC/51/SM 34 presented to the IWC Scientific Committee, May 1999.

Figure 3.—Winter ranges (minimum convex polygons of beluga whale satellite tag locations) of beluga stocks that winter in the Bering Sea. Polygons are drawn using January–March locations and years are denoted by the degree of shading. Figure reproduced from Citta et al. (2017).

(Fig. 3). Both returned to Norton Sound by mid-June 2013. Another beluga was tagged near Nome in November 2016. That animal spent November–December 2016 and January–April 2017 in western Norton Sound and adjacent waters of the eastern Bering Sea. In May–June it moved into Norton Sound and to the mouth of the Yukon River where it remained through October then moved again to western Norton Sound (ABWC[15]).

[15]Satellite tagging maps 2016-17 (avail. at http://www.north-slope.org/departments/wildlife-management/co-management-organizations/alaska-beluga-whale-committee/abwc-research-projects/satellite-maps-of-tagged-alaskan-beluga-stocks/satellite-tagging-maps-nov-2016).

Eastern Chukchi Sea

Studies conducted in the 1970's and early 1980's reported belugas congregating in nearshore waters and passes near Kasegaluk Lagoon typically in late June (Frost and Lowry, 1990; Seaman et al.[8]). Traditional knowledge confirmed this was a long-established summer concentration area (Huntington et al., 1999). Other than the annual return to the Kasegaluk Lagoon area, little was known about the distribution of the ECS stock until belugas were tagged with SDR's. During 1998–2012, 29 belugas were captured in conjunction with the annual subsistence hunt at Point Lay and equipped with SDR's that each provided location data for 5–522 days (Suydam, 2009; Hauser et al., 2014). Results showed that after leaving Kasegaluk Lagoon in July, whales moved into the northern Chukchi and Beaufort seas and some went far into the Arctic Ocean, penetrating heavy ice cover north of lat. 80° N (Suydam et al., 2001). Although belugas ranged widely in summer, both adults and subadults and both sexes were most often found in water deeper than 200 m, along and beyond the continental shelf break, including into very deep basin waters (Citta et al., 2013). They rarely

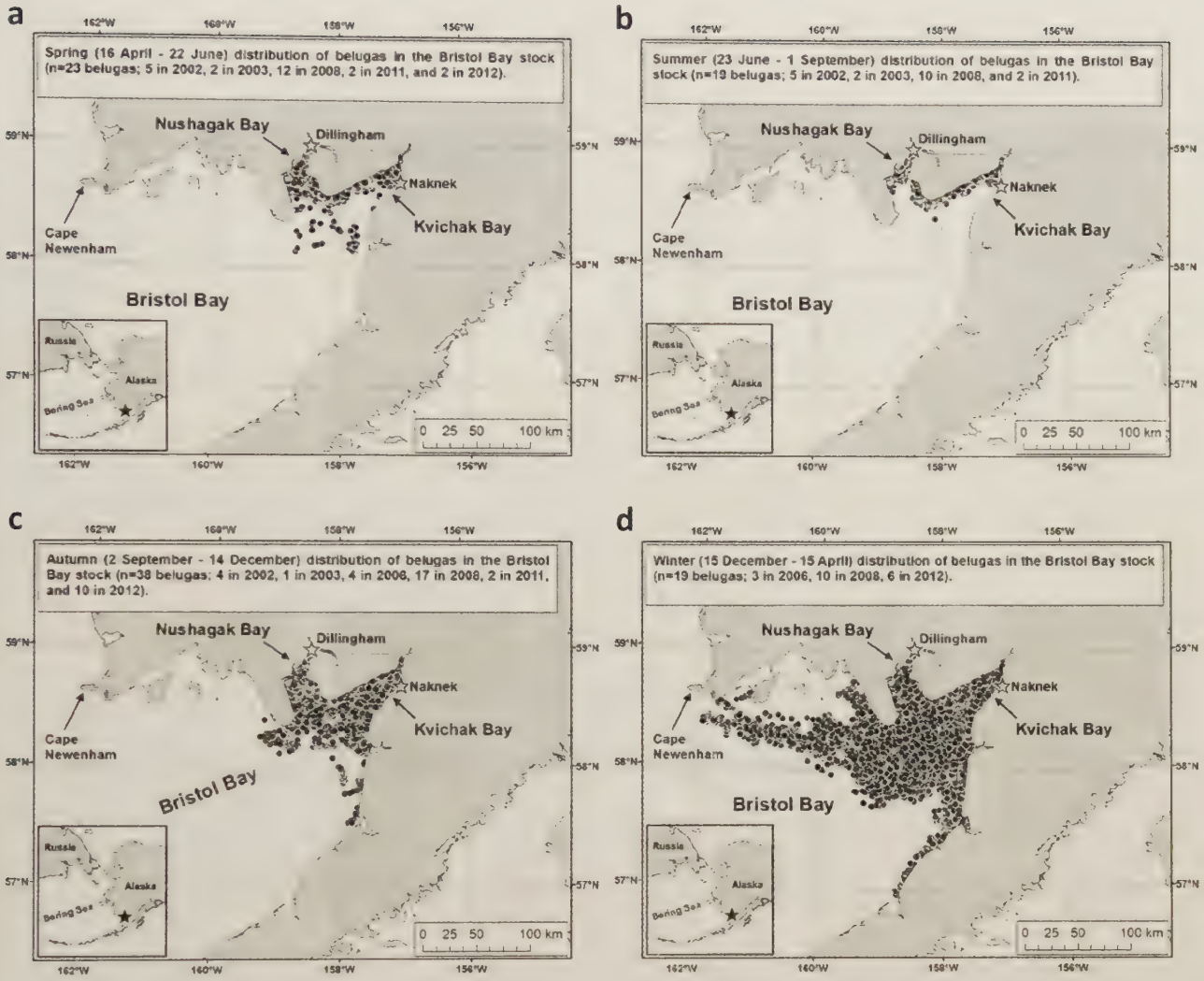
a
Spring (16 April - 22 June) distribution of belugas in the Bristol Bay stock (n=23 belugas; 5 in 2002, 2 in 2003, 12 in 2008, 2 in 2011, and 2 in 2012).
b
Summer (23 June - 1 September) distribution of belugas in the Bristol Bay stock (n=19 belugas; 5 in 2002, 2 in 2003, 10 in 2008, and 2 in 2011).
c
Autumn (2 September - 14 December) distribution of belugas in the Bristol Bay stock (n=38 belugas; 4 in 2002, 1 in 2003, 4 in 2006, 17 in 2008, 2 in 2011, and 10 in 2012).
d
Winter (15 December - 15 April) distribution of belugas in the Bristol Bay stock (n=19 belugas; 3 in 2006, 10 in 2008, 6 in 2012).
Nushagak Bay
Dillingham
Naknek
Kvichak Bay
Cape Newenham
Bristol Bay
Russia
Alaska
Bering Sea
0 25 50 100 km
162°W
160°W
158°W
156°W
59°N
58°N
57°N

Figure 4.—Locations for satellite tagged beluga whales in the Bristol Bay stock for (a) the spring (16 April–22 June), when salmon smolt, *Oncorhynchus* spp., and rainbow smelt, *Osmerus mordax*, are migrating; (b) the summer (23 June–1 September), when adult salmon are migrating; (c) the autumn, after the salmon migrations are complete (2 September–14 December); and (d) the winter (15 December–15 April), when sea ice is typically present. Data include those presented in Citta et al. (2016).

used shelf waters of the Beaufort Sea (Suydam, 2009; Clarke and Ferguson, 2018; Stafford et al., 2018). Hauser et al. (2014) used these data to describe beluga distributions and home ranges for July through November by which time the whales had moved southward through the Chukchi Sea to the Bering Strait region (Fig. 6). The six whales whose tags continued to transmit into late fall passed through Bering Strait in November–December then remained in the northern Bering Sea, between Bering Strait and St. Lawrence Island, into May (Fig. 3). One tag lasted long enough to re-enter the Chukchi Sea in late May and another stopped transmitting in early May, just south of Bering Strait (Citta et al., 2017).

Abundance and Trends

Bristol Bay

Aerial strip-transect surveys were conducted in Bristol Bay periodically during 1993–2005 (Lowry et al., 2008). Within each survey year, multiple flights covered the entire area where belugas have been observed during the survey period in late June and early July. Weather permitting, two surveys were conducted each day, both covering the entire summer range of this stock; only data from surveys with good viewing conditions were considered. Counts on individual flights during 1994–2005 ranged from 200–1,067, with annual averages of 362–623 (Fig. 7). Data from VHF transmitters attached to two BB belugas were used to estimate an availability correction factor of 2.75 (Frost et

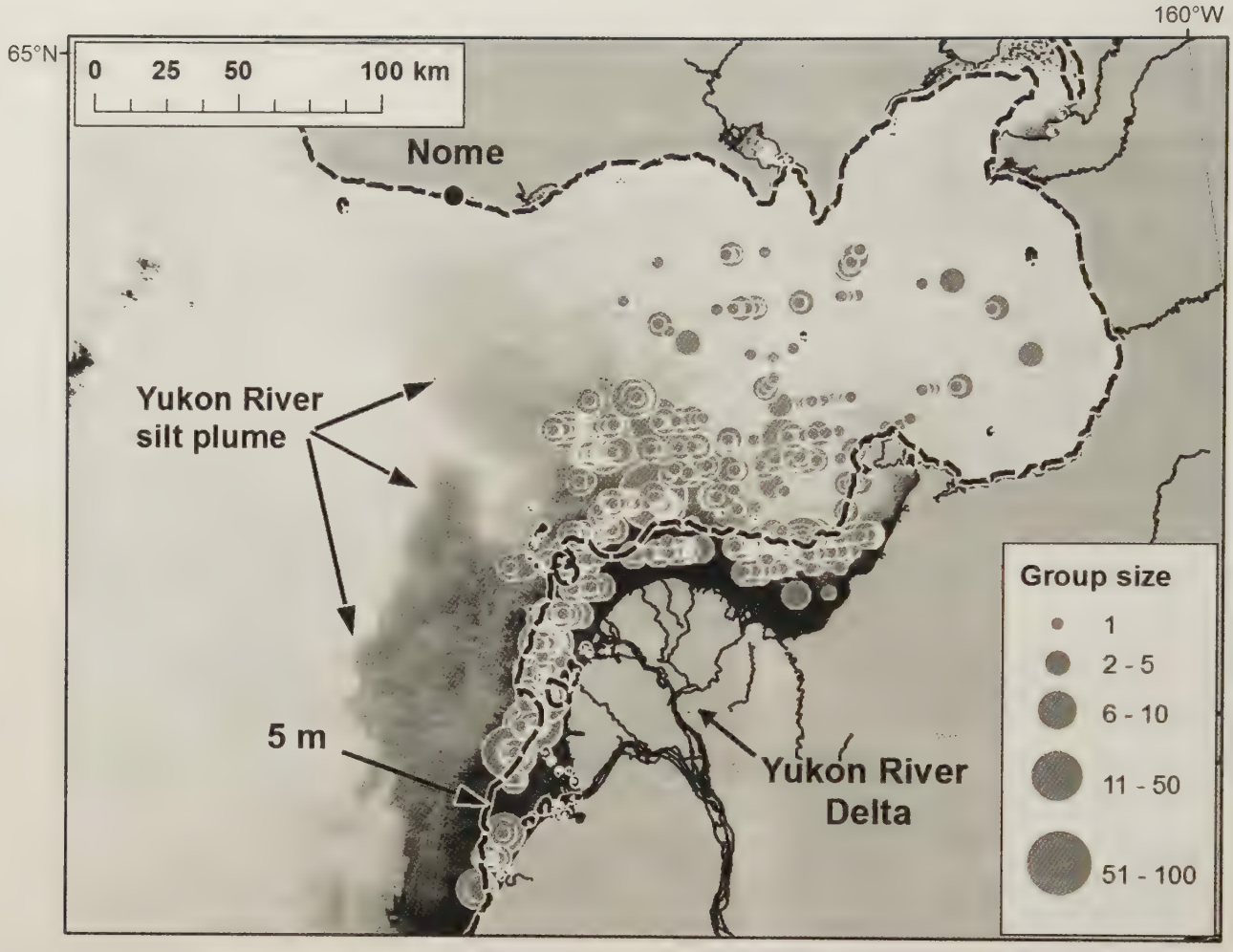

Figure 5.—MODIS image of Norton Sound and the Yukon River Delta taken from the Terra satellite on 17 June 2002. Dots are sightings of beluga whales made during aerial surveys 1995–2000. The dotted line indicates the 5 m isobath. The discharge plume of the Yukon River is darker where silt is more dense.

al., 1985), which was later revised to 2.62 (Frost and Lowry[16]). The estimate of abundance for the BB stock in the most current SAR is 1,926 (Muto et al., 2018) and was calculated by multiplying the average of counts from surveys in 2004 and 2005 (623) by the revised availability correction factor (2.62) and by a correction for the number of calves (1.18; Brodie, 1971), that are dark colored and difficult to see during surveys.

The ABWC conducted aerial surveys again in 2016 using the same methods as the 1993–2005 surveys (Citta et al., 2019). The average count from eight complete surveys of Bristol Bay in 2016 was 660 (coefficient of variation (CV) = 0.09; see Fig. 7). Using the corrections that have been applied in the past yields an estimated abundance of 2,040 (CV = 0.26) for 2016. The uncertainty in the correction factors has not been estimated; instead we have estimated the CV of the abundance estimate using the standard deviation of the counts divided by the average.

To further address the issues of abundance and correction factors, the ABWC and collaborators conducted a genetic mark-recapture study of the BB stock beginning in 2002. Estimates of abundance based upon mark-recapture methods are not reliant on estimating correction factors and provide an independent estimate of abundance. During 2002–11, the Alaska Department of Fish and Game (ADFG) worked with Alaska Native beluga hunters and collected skin samples using biopsy tips mounted on jab-sticks. Unique genotypes were determined by PCR amplification of mtDNA and eight microsatellite loci. Using a POPAN Jolly-

[16]Frost, K. J., and L. F. Lowry. 1995. Radio tag based correction factors for use in beluga whale population estimates. Working paper for Alaska, Beluga Whale Comm. Sci. Workshop, Anchorage, AK, 5–7 April 1995, 12 p. Avail. from North Slope Borough, Dep. of Wildlife Manage., Box 69, Barrow, AK 99723.

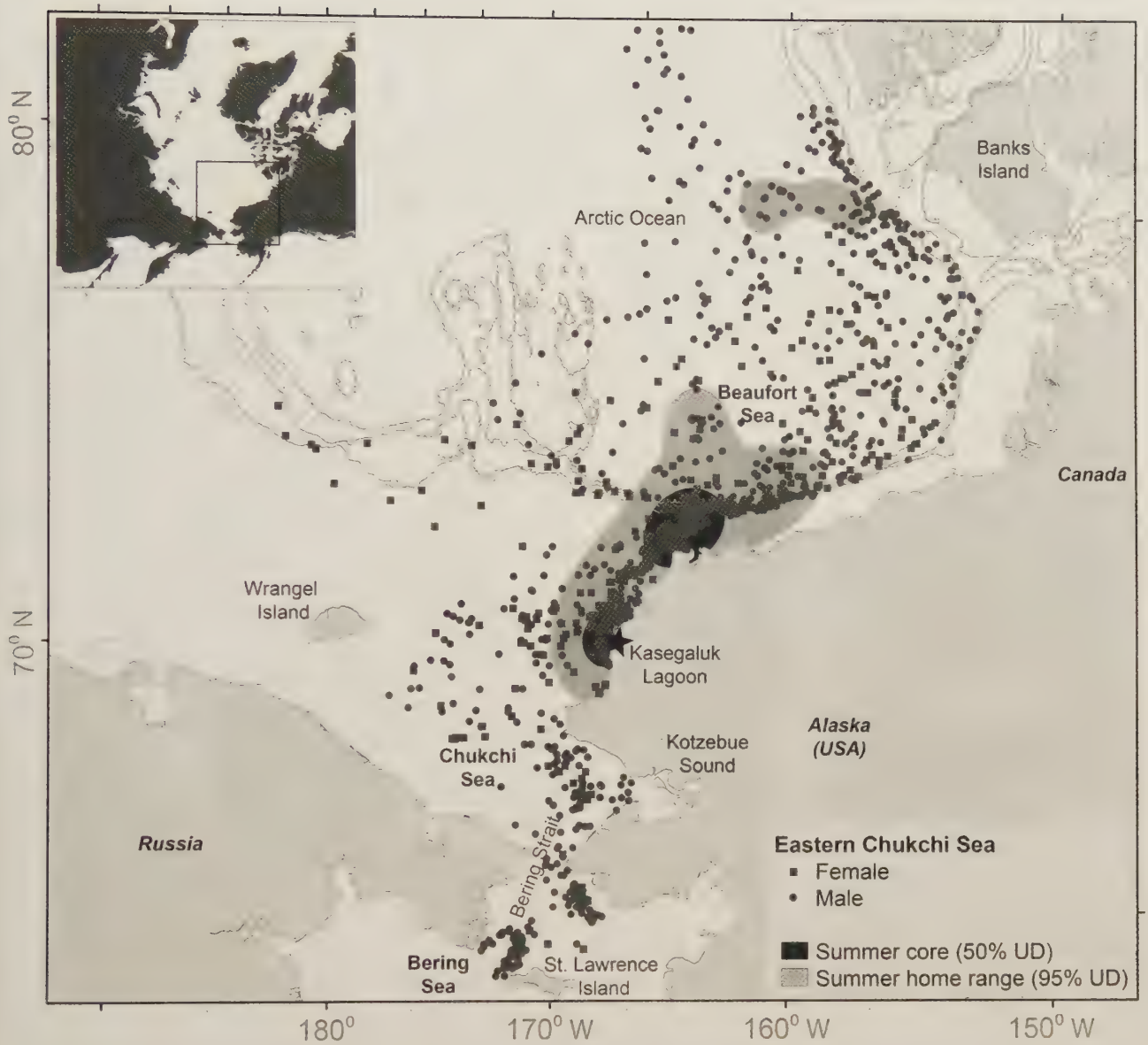

Figure 6.—Daily locations and home ranges of eastern Chukchi Sea belugas based on data collected during 1998–2012 from 29 whales equipped with satellite data recorders. Locations were collected during July–November; core and home ranges shown are for July and August, only. Modified from Hauser et al. (2014).

Seber model, abundance was estimated at 1,928 belugas (95% confidence interval (CI) = 1,611–2,337; Citta et al., 2018). Most belugas were sampled in Kvichak Bay at a time when belugas are also known to occur in Nushagak Bay. The pattern of genetic recaptures and data from belugas with SDR's indicated that belugas in the two bays regularly mix, suggesting the estimate of abundance likely applies to all Bristol Bay belugas. However, because it is likely that some belugas did not enter the sampling area during sampling, this estimate of abundance is best considered a minimum population size. Results from the genetic mark-recapture study are consistent with the estimate of 2,040 belugas from the 2016 aerial surveys.

A regression analysis of trend showed that the mean count of BB belugas increased 4.8% per year (95% confidence interval (CI) = 2.1–7.5%) over the 12-yr period, 1993–2005 (Lowry et al., 2008). The mean and range of counts made in 2016 is comparable to those in 2004–2005 (Fig. 7) suggesting that the population growth observed during 1993–2005 had slowed or ceased.

Eastern Bering Sea

To develop a population estimate for the EBS beluga stock, for which no directed efforts had ever been done,

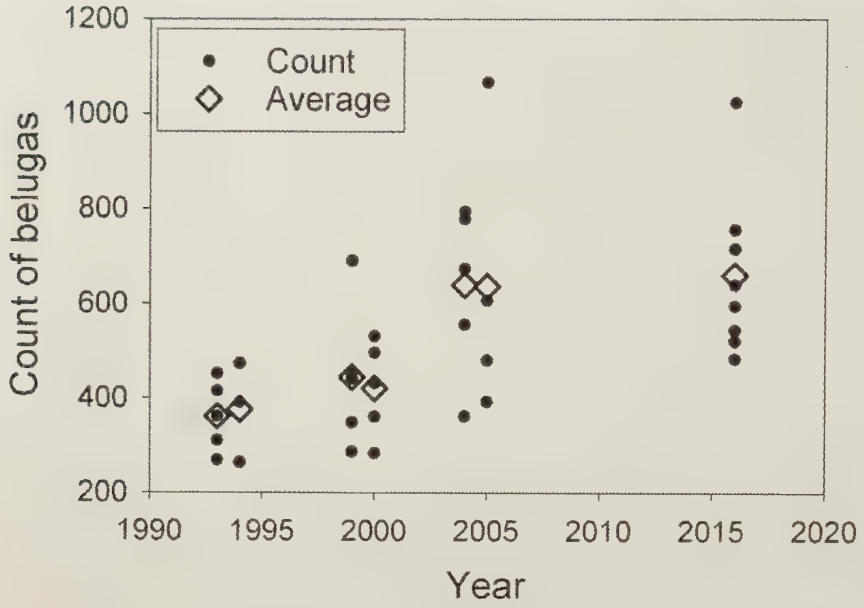

Figure 7.—Number of beluga whales observed during aerial surveys in Bristol Bay, 1993–2016. Black dots are the number of belugas counted during replicate flights and diamonds are the annual averages. For more information on aerial survey methods, see Lowry et al. (2008). The fit of linear versus other trends is statistically equivocal so we do not present a trend line here.

ABWC conducted aerial line-transect surveys in the Norton Sound/Yukon Delta region during 1993–95 (Lowry et al.[14]). These initial surveys provided distribution information and a preliminary abundance estimate that confirmed that the EBS stock was likely large (in the thousands) but the adequacy of survey coverage was questionable and confidence intervals of estimates were large. Additional line-transect surveys planned to cover all of Norton Sound and the Yukon Delta were flown in 1999 and 2000. Density and abundance were estimated from the 2000 survey, which had the most complete coverage of the area (Lowry et al., 2017a). In 2000, belugas were seldom seen in the northern portion of the Sound, thus the study area was restricted to the central and southern Sound and the northern and western Yukon Delta, and divided into four strata by latitude. The density estimated with the model that received most Akaike Information Criterion support was 0.121 belugas/km^2 and the number of belugas at the surface in the study area was estimated to be 3,497 (CV = 0.37). A generally accepted correction factor for availability of 2.0 (Reeves et al., 2011) was applied, resulting in an abundance estimate of 6,994 (95% CI = 3,162–15,472). In June 2017 NMFS conducted an aerial survey of this population following procedures similar to the 2000 survey (Fig. 8; Ferguson et al.[17]). Analysis of the survey data estimated a surface abundance of 4,621 belugas (CV=0.12, 95% CI =3,635–5,873); applying the multiplier of 2.0 to account for submerged whales yields an abundance estimate of 9,242 belugas (Ferguson et al.[17]). With only two population estimates 17 years apart, the current trend in abundance of the EBS stock is unknown; however, the two estimates are not significantly different, and we conclude that the population has not declined. These two estimates may be conservative because some belugas may have been outside the area surveyed (e.g., in the Yukon River) and the correction factor of 2.0 may be too low to account for the fraction of whales submerged in very turbid waters (Lowry et al., 2017a).

[17]Ferguson, M., K. Frost, A. Brower, A. Willoughby, C. Sims, and R. Suydam. 2018. Estimated abundance and distribution of eastern Bering Sea belugas from aerial surveys in 2017. 2018 Alaska Mar. Sci. Symp., Jan. 22–26, Anchorage, AK (Abstract only: avail. at https://www.alaskamarinescience.org/past-symposia/).

Eastern Chukchi Sea

An initial assessment of abundance of the ECS stock was made by using aerial photographs of belugas concentrated at Kasegaluk Lagoon passes to estimate that 2,282 belugas were present on 15 July 1979. The estimate included correction factors for whales outside the concentration area (+10%), whales too deep to be seen on the photographs (+20%), and dark colored yearlings that are difficult to see (+8%) (Seaman et al.[8]).

Subsequent aerial surveys were conducted in the 1980's and 1990's. On 8 July 1987, an aerial strip transect survey conducted over a large concentration of belugas near Point Lay counted 723 belugas; using correction factors of 2 or 3 to account for animals diving in relatively deep water it was estimated that there may have been 1,400–2,100 belugas in that group (Frost and Lowry, 1990). During 1989–91, aerial surveys of the concentration areas at Kasegaluk Lagoon resulted in single day counts ranging from 7 to 1,200 whales (Frost et al., 1993); offshore waters where belugas also occur were not surveyed. Correcting the 1,200 minimum count using VHF tag data from Bristol Bay for the proportion of belugas that were diving and thus not visible at the surface (2.62; Frost and Lowry[16]), and for the proportion of neonates and yearlings not seen due to small size and dark coloration (1.18; Brodie, 1971) produced a minimum abundance estimate of 3,710 belugas for the ECS stock. That estimate has been used in NOAA's SAR (Muto et al., 2016) and elsewhere (Laidre et al., 2015).

Surveys conducted during 1996–98 also found belugas farther offshore (Lowry et al.[18]), so subsequent efforts during 2001–03 included more off-

[18]Lowry, L. F., D. P. DeMaster, K. J. Frost, and W. Perryman. 1999. Alaska Beluga Whale Committee surveys of beluga whales in the eastern Chukchi Sea, 1996–1998. Rep. Int. Whal. Comm. SC/51/SM 33.

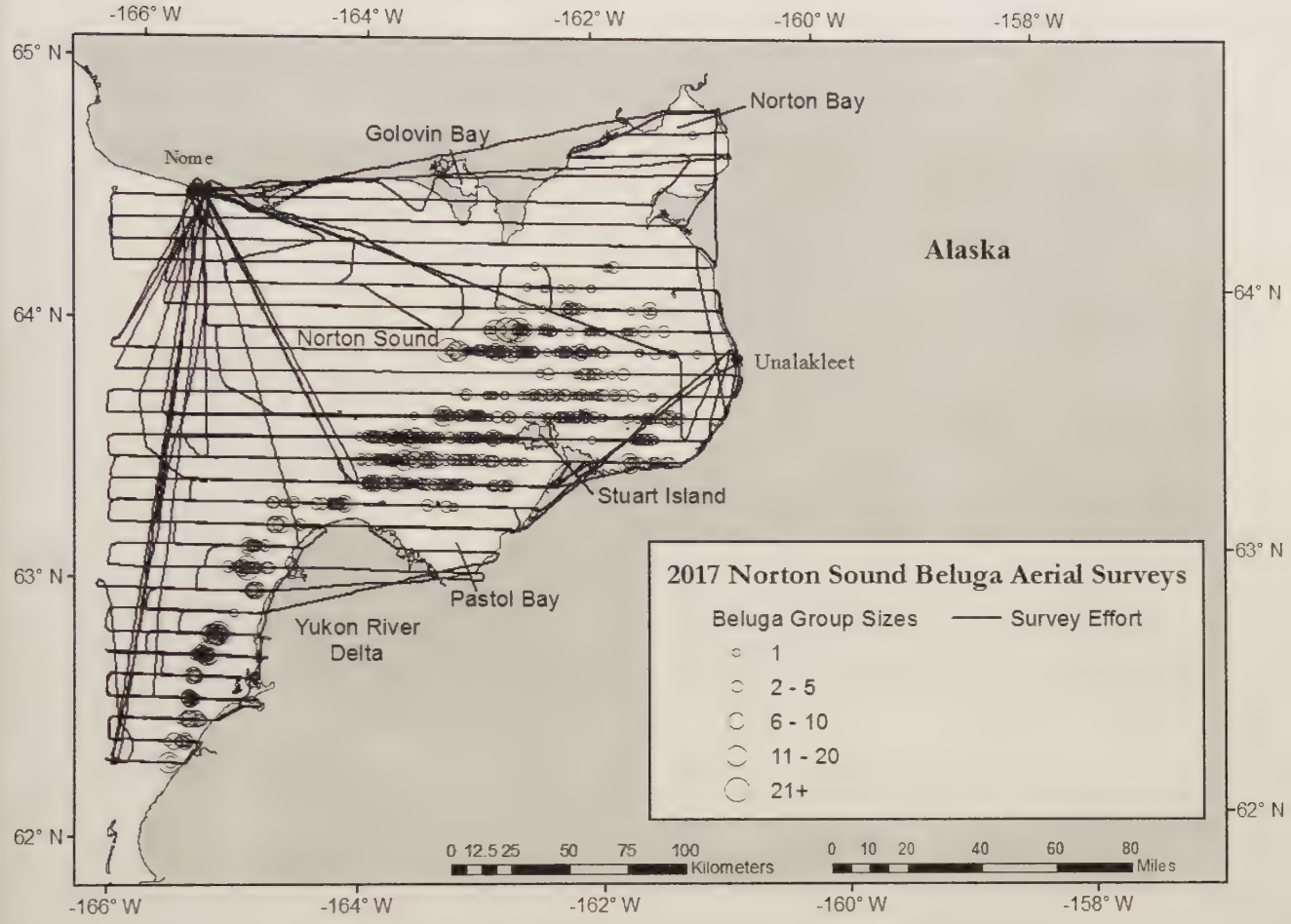

Figure 8.—Transects flown, strata used in the analysis, and beluga sightings made during NMFS beluga surveys in the eastern Bering Sea, June 2017.

shore flight lines. While belugas were occasionally sighted >50 km offshore, sightings were infrequent (Lowry and Frost[19,20]). Locations from whales tagged with SDR's at Kasegaluk Lagoon showed that many were beyond the limits of the area surveyed (Suydam et al., 2001). Aerial surveys for the ECS stock were suspended by the ABWC after 2003 due to the high cost relative to the low value of results for assessing abundance.

A different approach was clearly needed for estimating abundance of the ECS stock. An analysis of the SDR location data from belugas belonging to the ECS and Beaufort Sea stocks (Hauser et al., 2014) identified an area in the Beaufort Sea (long. 140° W to 157° W) and a period (19 July–20 August) when the two stocks did not overlap (Lowry et al., 2017b). In 2012, an aerial line-transect survey was conducted in that area during that period by the Aerial Surveys of Arctic Marine Mammals (ASAMM) project (Clarke et al.[21]) (Fig. 9). Analysis of those data estimated 5,547 (CV = 0.22) surface-visible belugas. SDR data were used to develop correction factors to account for animals that were missed because they were outside of the study area and those diving too deep to be seen, resulting in a total abundance estimate of 20,752 (CV = 0.70) (Lowry et al., 2017b). Additional surveys were conducted in 2013–16 and a full analysis of ECS beluga abundance using all available ASAMM data is underway.

Anthropogenic Removals

Subsistence Harvest

The ABWC, through its hunter delegates and collaborators, primarily the Bristol Bay Native Association and the North Slope Borough Department

[19]Lowry, L., and K. Frost. 2002. Beluga whale surveys in the Chukchi Sea, July 2002. Alaska Beluga Whale Comm., Rep. 02-2. Avail. from North Slope Borough, Dep. Wildl. Manage., Box 69, Barrow, AK 99723.

[20]Lowry, L. F., and K. J. Frost. 2003. Beluga whale surveys in the eastern Chukchi Sea, July 2003. AK Beluga Whale Comm. Rep. 03-1. Avail. from North Slope Borough, Dep. Wildl. Manage., Box 69, Barrow, AK 99723.

[21]Clarke, J. T., C. L. Christman, A. A. Brower, and M. C. Ferguson. 2013. Distribution and relative abundance of marine mammals in the northeastern Chukchi and western Beaufort Seas, 2012. U.S. Bur. Ocean Energy Manage., Annu. Rep. OCS-BOEM-2013-00117.

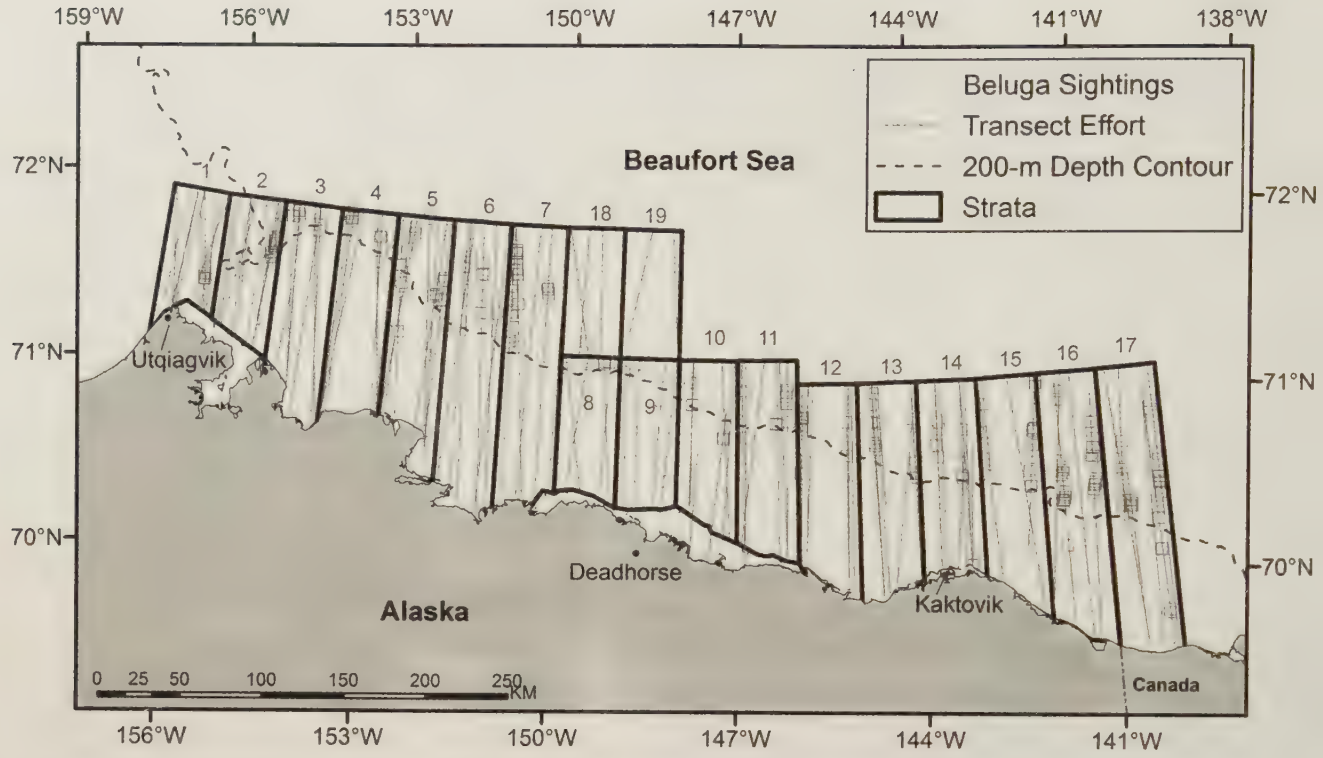

Figure 9.—Aerial surveys of Arctic marine mammals transect lines and sightings of eastern Chukchi Sea belugas in the Alaska Beaufort Sea during July–August 2012 (Lowry et al., 2017b).

of Wildlife Management, has collected data on Alaska Native subsistence harvests since 1987. Twelve villages harvested belugas in Bristol Bay in at least one year since 1987 (Table 1). During 1987–2006, the reported number of belugas landed each year by these villages combined averaged 17 (95% CI = 14–20, range 6–35; Fig. 10a). During 2007–16, the reported number of belugas landed each year by these villages combined averaged 23 (95% CI = 21–25, range 19–28; Fig. 10b). Reporting of belugas struck and lost in the Bristol Bay region is incomplete and total removals could be somewhat higher (Frost and Suydam, 2010; ABWC[22]). Although regression lines for both periods show a slight increasing trend, neither is statistically significant ($p = 0.64$ and 0.61).

Table 1.—Alaska communities that reported harvesting belugas from the Bristol Bay, eastern Bering Sea, or eastern Chukchi Sea beluga whale stocks in at least one year during 1987–2016.

Bristol Bay	Eastern Bering Sea		Eastern Chukchi Sea
	Norton Sound	Yukon River	
Aleknagek	Elim	Alakanuk	Point Lay
Clark's Point	Golovin	Chevak	Wainwright
Dillingham	Koyuk	Emmonak	
Egegik	Nome/Council	Hooper Bay	
Igiugig	Saint Michael	Kotlik	
Iliamna	Shaktoolik	Marshall	
Levelock	Stebbins	Mountain Village	
Manokotak	Unalakleet	Nunam Iqua	
Naknek	White Mountain	Pitka's Point	
Newhalen		Pilot Station	
New Stuyahok		Russian Mission	
Togiak		Saint Mary's	
		Scammon Bay	

Twenty-two villages report harvesting belugas from the EBS stock, 9 from Norton Sound and 13 from the Yukon Delta (Table 1). The average annual reported harvest for 1987–2006 was 152 belugas (95% CI = 123–181, range 31–281; Fig. 11a). During 2007–16, the average annual reported harvest was 191 belugas (95% CI = 171–211, range 126–236; Fig. 11b). The average annual reported harvest increased approximately 25% from 1987–2006 to 2007–16. Although this increase is statistically significant ($p = 0.04$), it is mostly due to better data being collected from more villages rather than more belugas being harvested (ABWC[22]). When the ABWC began meeting in 1988, there were two delegates representing Norton Sound

[22]Alaska Beluga Whale Committee (ABWC). Unpubl. data avail. from the North Slope Borough, Dep. Wildl. Manage., Box 69, Barrow, AK 99723.

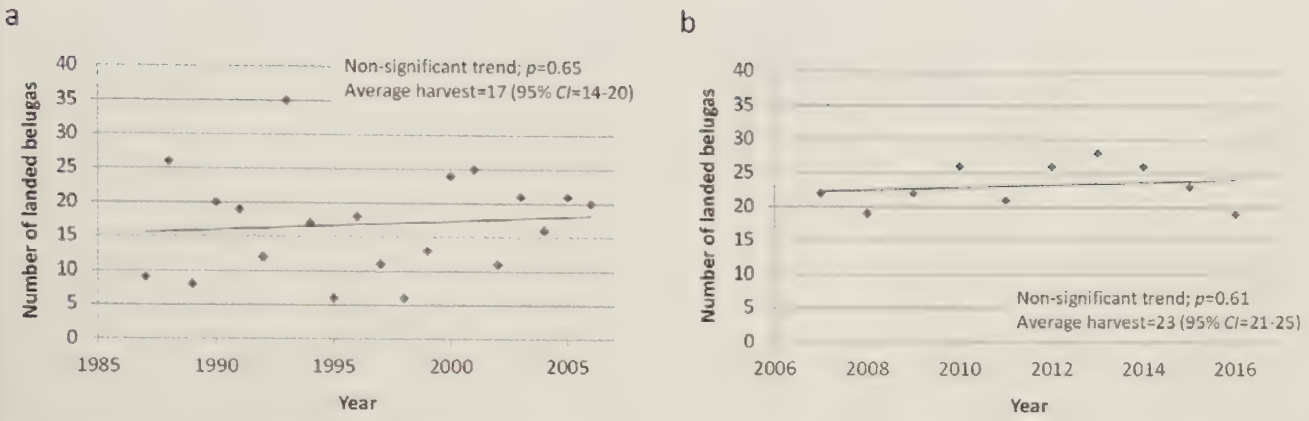

Figure 10.—(a) Number and trend of Bristol Bay belugas landed by subsistence hunters in Alaska during 1987–2006, and (b) during 2007–16). For more information on how harvest is documented see Frost and Suydam (2010).

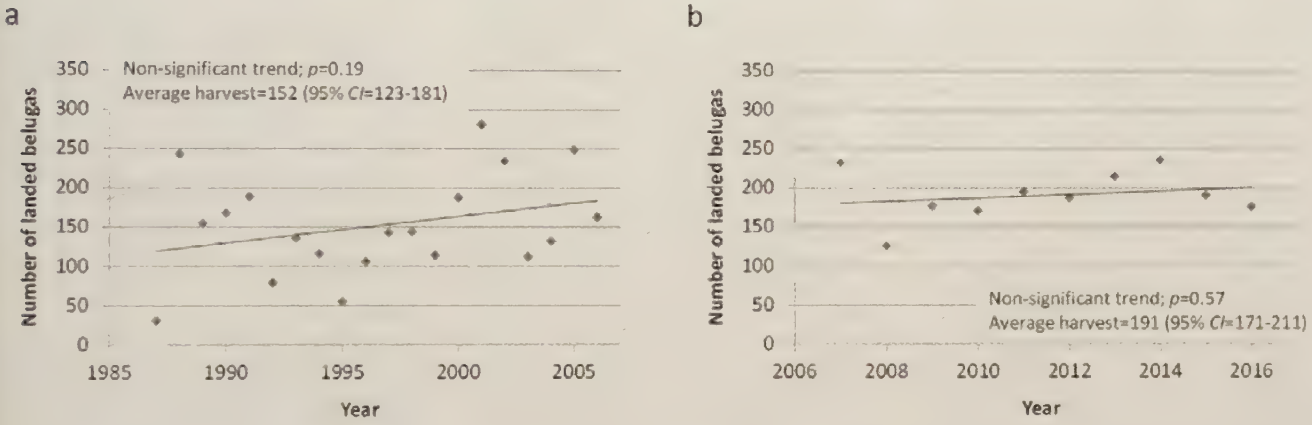

Figure 11.—(a) Number and trend of eastern Bering Sea belugas landed by subsistence hunters in Alaska during 1987-2006, and (b) during 2007–16. For more information on how harvest is documented see Frost and Suydam (2010).

and the Yukon Delta. Ten years later there were 10, and currently there are 15 communities represented by delegates who attend meetings and report harvest data for their own and nearby villages. Intermittent struck and lost data are available for the EBS stock for 17 villages during the last 5 years. During those years, the number of belugas reported to be struck and lost averaged 13% of the landed but this is based on incomplete data (ABWC[22]).

Harvest of belugas from the ECS stock occurs mainly at the villages of Point Lay and Wainwright. The average annual reported harvest for 1987–2006 was 48 belugas (95% CI = 37–59, range 0–86; Fig. 12a). During 2007–16, the average annual harvest was 57 belugas (95% CI = 38–76, range 14–121, Fig. 12b). The slight positive trend for 1987–2006 is not statistically significant (p = 0.93). The apparent strong negative trend for 2007–16 is not statistically significant either (p = 0.15) because of substantial annual variations in harvest. Both Point Lay and Wainwright usually conduct drive hunts, and typically only one or two whales at most are struck and lost during those hunts (ABWC[22]).

Fishery Bycatch

In the United States, commercial fisheries operating in federal waters (3–200 nmi. offshore) that may take marine mammals as bycatch are regularly monitored. Fishery observers have monitored the groundfish trawl, longline, and pot fisheries off western Alaska and during 2011–15 only one beluga mortality was reported (Muto et al., 2018).

During the Bristol Bay sockeye salmon fishery (managed by the State of Alaska) in late June and early July, belugas are observed swimming near fishing operations, suggesting they could be caught in the salmon set gillnet and drift gillnet fisheries that occur in the inner bays. During May–July 1983, Frost et al.[12] conducted beach surveys in the inner bays from airplanes and boats and found 27 dead belugas, at least 12 of which were attributed to bycatch in nets. The commercial gillnet fisheries have never been monitored for

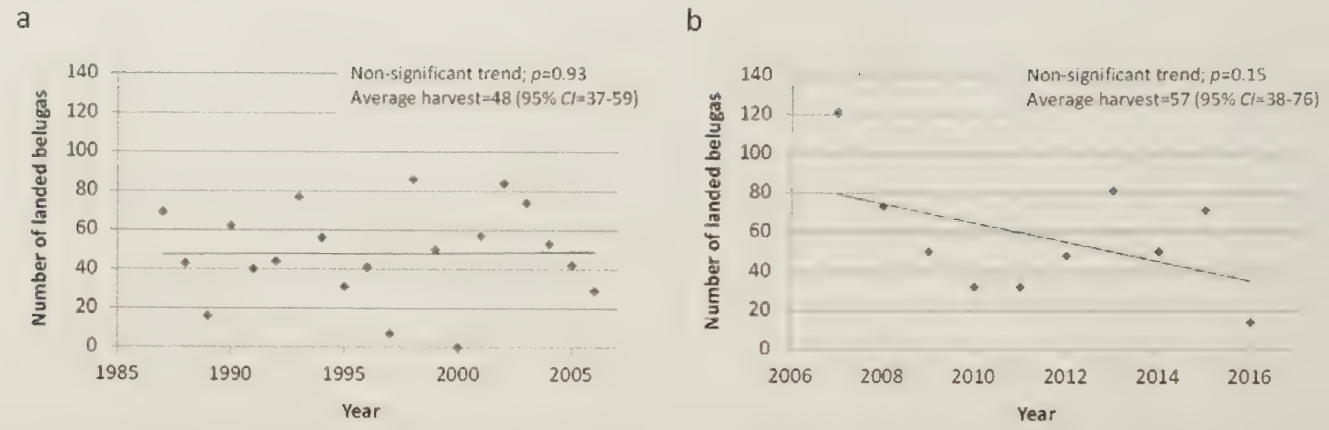

Figure 12.—(a) Number and trend of eastern Chukchi Sea belugas landed by subsistence hunters in Alaska during 1987–2006, and (b) during 2007–16. For more information on how harvest is documented see Frost and Suydam (2010).

bycatch and there are no current data on incidental take. There is also a large subsistence gillnet fishery for salmon in Bristol Bay in which four belugas were reported taken during 2013–14 (Muto et al., 2018). Three of those takes were reported as subsistence harvest as they were used for subsistence purposes by Alaska Natives.

State-managed commercial, personal use, and subsistence gillnet fisheries for salmon or whitefish, *Coregonus* spp., occur in nearshore waters in the range of the EBS and ECS stocks. Although these fisheries are a potential source of bycatch mortality and bycatch is not systematically monitored, it is likely that only a few whales are taken each year (ABWC and NSBDWM[22]).

Stock Status

None of the western Alaska beluga stocks are designated as "depleted" or "strategic" under the U.S. Marine Mammal Protection Act (MMPA), nor are they listed as "threatened" or "endangered" under the U.S. Endangered Species Act (Muto et al., 2018). In an assessment done in 2008, the International Union for the Conservation of Nature listed belugas as a species "Near Threatened" and also noted that the various subpopulations should be assessed separately (Jefferson et al.[23]). A revised assessment published on the IUCN Red List in 2017 listed the species as "Least Concern" (Lowry et al.[24]).

Under the 1994 reauthorization of the MMPA, the PBR for a stock is defined as the product of the minimum population estimate, one-half the maximum theoretical net productivity rate, and a recovery factor: PBR = $N_{MIN} \times 0.5R_{MAX} \times F_R$ (Wade and Angliss, 1997). N_{MIN} is the lower 20th percentile of a log-normal distribution that represents the minimum number of whales after accounting for uncertainty in the estimates. F_R is equal to 1.0 when a population is stable or increasing and can be adjusted lower for declining trends or high uncertainty. Although the system was designed only to evaluate fishery bycatch, PBR can be compared to all anthropogenic removals as a conservative measure of the sustainability of those removals.

The only data on maximum net productivity for belugas comes from the BB stock where the estimated rate of increase over the 12-yr period 1992–2005 was 4.8%/yr (Lowry et al., 2008), but that may not be the maximum rate because subsistence harvest was occurring during that period. The measured value for the BB stock is close to the 4%/yr that is used in the NOAA SAR as the default maximum net productivity rate for cetaceans (Wade, 1998), and we use the value of 4.8%/yr in the calculations below.

Bristol Bay

Based on 2004–05 average counts from aerial surveys, Muto et al. (2018) estimated the minimum population size for the BB stock as 1,565 belugas using a CV of 0.25. They did not estimate PBR because the abundance data were more than 8 years old. Using the rate of increase of 4.8%/yr (Lowry et al., 2008) as an estimate of R_{MAX}, we calculated PBR using both the 2016 aerial surveys and the mark-recapture estimate of Citta et al. (2018). For the 2016 aerial surveys, N_{BEST} = 2,040; CV = 0.26; N_{MIN} = 1,645, R_{MAX} = 0.048; F_R = 1.0; PBR = 39. For the mark-recapture estimate, which covers the period 2002–2011, N_{BEST} = 1,928; CV = 0.1; N_{MIN} = 1,773, R_{MAX} = 0.048; F_R = 1.0; PBR = 43. The current average annual subsistence harvest of 23 belugas is approximately 59% of PBR calculated from the 2016 survey data and 53% of PBR as calculated from the mark-recapture study. Some bycatch in fisheries is known to occur (Muto et al., 2018); howev-

[23]Jefferson, T. A., L. Karkzmarski, K. Laidre, G. O'Corry-Crowe, R. Reeves, L. Rojas-Bracho, E. Secchi, E. Slooten, B. D. Smith, J. Y. Wang, and K. Zhou. 2012. *Delphinapterus leucas*. The IUCN Red List of Threatened Species 2012: e.T6335A17690692 (avail. at https://doi.org/10.2305/IUCN.UK.2012.RLTS.T6335A17690692.en). Downloaded on 03 Feb. 2017.

[24]Lowry, L., R. Reeves, and K. Laidre. 2017. *Delphinapterus leucas*. The IUCN Red List of Threatened Species 2017: e.T6335A50352346 (doi: https://doi.org/10.2305/IUCN.UK.2017-3.RLTS.T6335A50352346.en).

er, bycatch has likely been too small for total removals to exceed PBR because this stock has been increasing or stable.

Eastern Bering Sea

In the 2017 SAR, the PBR for the EBS stock was considered to be "undetermined" because the most current abundance estimate was more than 8 years old (Muto et al., 2018). However with the 2017 abundance estimate of 9,242 (CV = 0.12) (Ferguson et al.[17]), PBR can be calculated as follows: N_{BEST} = 9,242; CV = 0.12; N_{MIN} = 8,357, R_{MAX} = 0.048; F_R = 1.0; PBR = 201. It should be noted that this estimate includes an arbitrary correction factor for missed animals of 2.0 that has no associated CV. The average annual subsistence removal for the past 10 years (191) is below this calculated PBR; if struck and lost is considered, total annual removals would be 215, or 7% above PBR. However, the abundance estimate is thought to be low because the survey did not include all potential beluga habitat (e.g., the Yukon River itself), dark gray animals (calves) were particularly hard to see in muddy water coming from the Yukon, and the analysis did not account for all aspects of perception bias. Regardless of the uncertainty in the estimate of abundance and PBR, that the harvest is approximately equal to PBR is of concern and the ABWC requested that NOAA conduct line-transect surveys on a regular basis. Although coastal fisheries are not regularly monitored for incidental take of belugas, all indications are that takes of belugas from this stock are very infrequent (Muto et al., 2018).

Eastern Chukchi Sea

In the 2017 SAR (Muto et al., 2018), data provided in Lowry et al. (2017b) were used to estimate PBR for the ECS stock as follows: N_{BEST} = 20,752; CV = 0.70; N_{MIN} = 12,194, R_{MAX} = 0.04; F_R = 1.0; PBR = 244. Using R_{MAX} = 0.048 we estimate PBR as 293. The average annual Alaska Native subsistence harvest from the ECS stock for the last 10 years (57 belugas) is about 19% of PBR. Although coastal fisheries are not regularly monitored for incidental take of belugas, all indications are that such takes are very infrequent and therefore anthropogenic removals from the ECS beluga stock are sustainable.

Threats

Sea Ice and Climate Warming

Because belugas are an ice-associated species, there is concern about possible impacts of climate warming and associated loss of sea ice habitat. Laidre et al. (2015) analyzed remotely sensed sea ice data and found little change in the duration of the reduced ice (summer) period in the Bering Sea from 1979 to 2013. In contrast, they found that the duration of the reduced ice period increased by 44 days in the Chukchi Sea and 52 days in the Beaufort Sea over the same period. These data suggest that ECS belugas are more susceptible to possible impacts of sea ice change, while EBS and BB belugas may be less at risk. However, we note that ABWC members who live and hunt in these regions report that Bering Sea ice has formed later, melted earlier, and not been as thick as in previous decades. They also report that, since 2013, some areas have remained ice free through the winter and in other areas there has been extremely rapid retreat of ice in the spring (ABWC[22]).

Belugas do not occur in regions without at least seasonal sea ice suggesting a strong, if not obligate, connection. However, some subpopulations spend many months far from ice while others spend most of their time in or near ice of concentrations up to 90%, indicating substantial flexibility in the species as a whole (Hauser et al., 2017). Belugas that occupy ice covered areas may do so for feeding on abundant ice-associated species, such as arctic cod, *Boreogadus saida* (Loseto et al., 2009; Hauser et al., 2015). Changes in the distribution and characteristics of sea ice will result in changes in productivity and in the types and abundance of prey species (Laidre et al., 2008; Haug et al., 2017), but the potential costs or benefits to belugas of such changes are not known. Killer whales, *Orcinus orca*, prey on belugas (Frost et al., 1992) and concentrated sea ice may provide belugas some degree of refuge from predation. There is good evidence that killer whales are expanding into Arctic regions where sea ice has been declining (Higdon and Ferguson, 2009; Ferguson et al., 2010). Belugas are susceptible to entrapment in sea ice when conditions change rapidly and, if they cannot escape, they may die or be preyed upon by polar bears, *Ursus maritimus*, and humans (Lowry et al., 1987; Heide-Jørgensen et al., 2002, 2013; Laidre and Heide-Jørgensen, 2005).

There have been three studies that specifically address the potential influence of changes in ice conditions on western Alaska belugas. O'Corry-Crowe et al. (2016) analyzed long-term sighting and genetic data on belugas in the Bering, Chukchi, and Beaufort seas in conjunction with multi-decadal patterns of sea ice to investigate the influence of sea ice on spring migration and summer residency patterns. Although substantial variations in sea ice conditions were found across seasons, years, and sub-regions, the pattern of beluga migration and residency was quite consistent. Those results suggest that belugas can accommodate some changes to sea ice conditions and will return to traditionally used areas. However, they also observed anomalous movement patterns that coincided with years with anomalously low sea ice coverage, and in one case with an increase in killer whale sightings and predation on belugas, indicating that behavioral shifts may be driven by changing sea-ice and associated changes in resource dispersion and predation risk. Hauser et al. (2016) compared the timing of the autumn migration of ECS and Beaufort Sea belugas during the periods 1993–2002 and 2004–12. They found that, in the later period, ECS beluga migration during autumn from the Beaufort and Chukchi seas was delayed by 2 to > 4

weeks, but that Beaufort Sea belugas did not shift migration timing between periods. Hauser et al. (2018) applied resource selection models to movements of ECS and Beaufort Sea belugas during 1990–2014 and found that, although sea ice has declined, belugas are generally found in the same locations and speculated that bathymetric features were better predictors of summer habitat use than sea ice concentration. Hauser et al. (2018) also found that ECS belugas were making longer, deeper dives in recent years and speculated that this might be due to changes in sea ice concentration.

A long-term study of belugas off West Greenland found that belugas responded to changing sea ice by shifting their distribution and that abundance increased during a period of generally declining ice cover (Heide-Jørgensen et al., 2010). The authors concluded that "Global warming and sea-ice declines may pose less of a problem for belugas than to other Arctic marine mammals." Laidre et al. (2008) also concluded that, on a range-wide basis, the beluga would be the Arctic cetacean least sensitive to climate change because of their wide distribution, diverse diet, and flexible habits.

It is possible that climate warming may have effects on belugas beyond those linked to changes in sea ice. Specific annual summering areas likely have particularly suitable environmental conditions such as water temperature and substrate. Those areas may be important for feeding, molting, calving, and avoidance of killer whales (Frost and Lowry, 1990; Laidre et al., 2008). Little attention has been given to measuring the specific features of these areas or projecting how those features may change with climate warming. Warmer water may allow the expansion of new prey species into the belugas' range or cause traditionally used prey to move elsewhere. Although some beluga stocks may focus on certain prey, such as Arctic cod or Pacific salmon, belugas are capable of consuming a wide variety of prey and are best classified as generalist predators. In their examination of stomach contents from harvested belugas, Quakenbush et al. (2015) found a minimum of 14 species of fish and invertebrates from BB belugas, 22 species from EBS belugas, and 15 species from ECS belugas. Belugas clearly show flexibility and adaptive capacity making it particularly difficult to predict how they will be affected by climate change.

Fishery Interactions

No incidental mortalities or injuries to belugas were reported by fishery observers that monitored the groundfish trawl, longline, and pot fisheries off western Alaska during 1990–97 (Muto et al., 2016) and only one was reported during 2011–2015 (Muto et al., 2018). Other observations show that belugas have been caught in commercial and subsistence salmon fisheries that occur along the coast, but overall there are no reliable data on incidental take. Although beluga mortalities due to fisheries occur in Bristol Bay, they did not prevent population growth between 1993 and 2005 (Lowry et al., 2008). We suspect that unless there is a major change in how or where commercial gillnet fisheries occur, these fisheries will not be a threat to the long-term sustainability of belugas. Nevertheless, monitoring levels of bycatch in commercial and subsistence gillnet fisheries is warranted.

In Bristol Bay, belugas feed on salmon when they are available. They feed both on smolt migrating out of river systems and on adults returning to the rivers to spawn (Brooks et al.[1]). Because salmon runs were severely depressed in Bristol Bay in the 1950's, an effort was made to deter belugas from river mouths by playing underwater sounds recorded from killer whales (Fish and Vania, 1971). Efficacy of this effort was equivocal, and the "beluga spooker" program ended after 1978. In the early 1980's after salmon runs had largely recovered, Frost et al.[12] conducted additional studies in Bristol Bay and concluded that beluga predation was equal to less than 1% of the commercial catch of adult sockeye salmon and less than 5% of the smolt outmigration.

Belugas that summer in the Yukon Delta region also feed on Pacific salmon. This is a large stock of whales that may consume a substantial portion of some Yukon River salmon runs, thereby potentially impacting catches in commercial and subsistence fisheries and the trophic structure of the ecosystem (Lowry et al., 2017a).

Industrial Activities

An increase in the duration of the open water season and the decline in multi-year sea ice have generated concern that increases in oil and gas exploration and development, and shipping may have negative consequences for belugas (Reeves et al., 2014). Most oil and gas activity within the range of western Alaska belugas currently occurs over the continental shelf in the Beaufort Sea, although from 2006 to 2015 there was also considerable activity in the Chukchi Sea. In the Beaufort Sea, the distribution of ECS belugas is predominantly limited to offshore areas, near the continental shelf break and in the Arctic Basin. At present, oil and gas activity in the Alaska portion of the Beaufort Sea is far inshore of where belugas typically range (Suydam et al.[25]). In 2016, most of Bristol Bay and the U.S. portion of the Chukchi Sea were removed from future leasing by Presidential order, but that order was rescinded in 2018. Also, there are still active oil and gas lease areas in Alaska's Beaufort Sea and in the Russian portion of the Chukchi Sea, so impacts from oil spills and shipping activity are still possible in those areas.

Although shipping is increasing with declining sea ice (Eguíluz et al., 2016; Pizzolato et al., 2016), belugas are not known to be susceptible to ship strikes, even in congested areas such as the St. Lawrence River (King-

[25]Suydam, R. S., L. F. Lowry, and K. J. Frost. 2005. Distribution and movements of beluga whales from the eastern Chukchi Sea stock during summer and early autumn. Final report to Coastal Marine Institute, Univ. Alaska, Fairbanks, AK, 39 p.

sley, 2002). Furthermore, factors in addition to sea ice, such as where resources are being developed and commodity pricing, determine shipping trends (Brigham, 2011; Bensassi et al., 2016; Pizzolato et al., 2016). As such, predicting how patterns in shipping will change is difficult, as is how belugas will respond to those changes.

Impacts to belugas in the far north from noise associated with shipping, including icebreaking (e.g., Finley et al., 1990), or other industrial activities, may be more of a concern than ship strikes. Studies suggest that belugas may avoid sources of noise (e.g., Finley et al., 1990) or change their behavior in response to noise, by increasing swim speed, making longer dives, or foraging less (e.g., Blane and Jaakson, 1994; Kendall and Cornick, 2015). However, other studies suggest that belugas may habituate to anthropogenic noise or fishing boats (e.g., Fish and Vania, 1971). The population-level impacts of noise and shipping are poorly understood and what these studies, conducted in places such as Cook Inlet (Kendall and Cornick, 2015) or the St. Lawrence Estuary (Blane and Jaakson, 1994), may mean for belugas in Arctic shipping lanes is unclear. Dedicated studies are needed to investigate how belugas will respond to anthropogenic noise in Arctic shipping lanes.

There are currently two proposed mines in southwestern Alaska that have the potential to affect beluga habitat. A large copper, gold, and molybdenum mine, known as the Pebble Mine, is proposed for the headwaters of the Nushagak and Kvichak rivers, which flow into bays that are the primary summer habitat of the BB beluga stock. This mine would process ore using a cyanide solution and would produce effluents that would be toxic to fish and other organisms if leaked into the river systems. The Final Environmental Impact Statement is due to be released by the Army Corp of Engineers in summer 2020. The other notable mine, the Donlin Mine, is in the Kuskokwim River drainage and poses similar risks to fisheries. Although Kuskokwim Bay does not contain the primary summer range of any beluga stock, EBS belugas are known to frequent the area in winter. The Donlin Mine has been granted federal permits but is still acquiring state permits.

Conclusions

The BB beluga stock is relatively small (approximately 2,000 animals), but its abundance and trend are periodically monitored and the stock appears to have increased between 1993 and 2005, and may now be stable. The most conservative estimate of PBR for this stock (39) is more than the average annual Alaska Native subsistence harvest over the last decade (23). Although there is little information regarding incidental take or struck and lost rates, the population has increased in recent decades, suggesting that all sources of mortality have not been significant (Lowry et al., 2008).

The EBS beluga stock is quite large, and aggregates off the mouths of the Yukon River and in Norton Sound every June. The most recent abundance estimate of over 9,000 is based on data collected in 2017 and relies on an arbitrary correction factor to account for availability bias. Additional work (e.g., SDR tagging) is needed to develop better correction factors. The average annual reported subsistence harvest (191) does not exceed PBR calculated from this abundance estimate (201) however when struck and lost estimates are included it does. While available scientific data do not allow an estimation of population trend, local and traditional knowledge indicate that there has not been a noticeable decrease in abundance or availability of EBS belugas in recent years (ABWC[22]).

The ECS beluga stock is large, estimated as approximately 20,000 belugas (Lowry et al., 2017b). The average annual subsistence harvest (57) is well below PBR (293). ECS belugas are not at immediate risk from anthropogenic activities or climate change, however, additional monitoring of population size and trend, subsistence harvest, and health of belugas is warranted.

There are currently few identified threats to persistence of western Alaska beluga stocks, although climate warming, declines in sea ice, and industrial activities related to resource development are of concern and could pose challenges in the future.

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Structure and Assessment of Beluga Whale, *Delphinapterus leucas*, Populations in the Russian Far East

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ABSTRACT—In 2000, the International Whaling Commission conducted a global assessment of beluga whales, Delphinapterus leucas. *Following this assessment, five beluga stocks were recognized in Russian Far East waters: Western Chukchi-East Siberian Sea, Anadyr Gulf, Shelikhov, Sakhalin-Amur, and Shantar. This paper provides a revised assessment of beluga abundance, distribution, and population structure in the Russian Far East. This region encompasses the Okhotsk Sea, and the coastline of the Chukotka Autonomous Region (CAR), which includes the western Bering, western Chukchi, and eastern East Siberian seas. Published results of genetic analysis are updated with our original unpublished data. Based on information available to date, we propose recognizing seven beluga stocks in the Russian Far East. Five stocks in the Okhotsk Sea: 1) Sakhalin-Amur, 2) Ulbansky, 3) Tugursky, 4) Udskaya, 5) Shelikhov, and two stocks in the CAR: 6) Anadyr, and 7) Bering-Chukchi-Beaufort (BCB). Natural and anthropogenic threats to these stocks are described and include ice entrapment, over-fishing of key prey, live captures for aquaria, bycatch in fisheries, exposure to effluent, and seismic and military activities.*

Introduction

In the Russian Far East, the beluga, *Delphinapterus leucas*, or white whale, occurs in the Okhotsk Sea and along the coastline of the Chukotka Autonomous Region in the western Bering, western Chukchi, and eastern East Siberian seas (Fig. 1). From late 1920's to the dissolution of the Soviet Union in 1991, Soviet scientists conducted extensive studies on this species' abundance and distribution, mainly because belugas were hunted commercially (Kleinenberg et al., 1964; Matishov and Ognetov, 2006). In 2000, scientific information on belugas in Russian waters was reviewed and summarized for the global assessment of the species by the Scientific Committee of the International Whaling Commission (IWC, 2000). At that time, five beluga stocks in Russian Far-Eastern waters were recognized: Western Chukchi-East Siberian Sea (stock no. 25), Anadyr Gulf (26); Shelikhov (27); Sakhalin-Amur (28), and Shantar (29). The delineation of Stock 25 was questioned by some experts, who, based on satellite tracking data, suggested belugas migrating along Chukotka Peninsula coast belonged to United States or Canadian stocks (i.e., Eastern Bering Sea (stock no. 3), Eastern Chukchi Sea (4), or Beaufort Sea (or Eastern Beaufort) (5)). For stocks 25 and 26, no abundance estimates were provided, and the Okhotsk Sea beluga population (comprised of stocks 27, 28, and 29) was estimated at 18,000–20,000 (IWC, 2000).

Apart from nonexistent or methodologically poor abundance estimates, no genetic information was available at that time, and migration routes and winter grounds remained mostly unknown. Stock delineation was based solely on summer distribution and local movement patterns.

Since the IWC (2000) assessment, and a break in research in the 1990's following the dissolution of the Soviet Union, extensive beluga studies have been resumed in the Russian Far East in 2005. Currently management of marine resources in Russia, including belugas, is not based on the species population structure, but rather on geographically defined fishing zones. Our studies in the Okhotsk Sea have led to the Russian Federal Agency of Fisheries and the Ministry of Agriculture recognizing the necessity to consider stock distribution when issuing total allowable takes (TAT) in this region (Ministry of Agriculture, Order N 533, 27 October 2017). An updated assessment of beluga population structure would be important for effective and sustainable management.

Here, we review and summarize our previously published research results and present updated genetic results on the Far Eastern beluga population structure and status, to provide a basis for effective conservation and sustainable management. A working version of this paper was originally presented and discussed at the Global Review of Monodontids (GROM)[1] meeting held in March 2017 (Hobbs et al., 2019, provide an overview of the meeting outcomes).

Methods

Genetics

Our use of the term "biological population," or population, is defined as a group of individuals who interbreed and are genetically isolated from other biological populations due to geographical, behavioral, or any other reasons. In summer months, many beluga populations seasonally break into discrete, relatively resident "nursery aggregations" (a synonym to the term "reproductive aggregation"

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[1]GROM (https://nammco.no/topics/report-global-review-monodontids-now-available/ accessed 9 Aug. 2018).

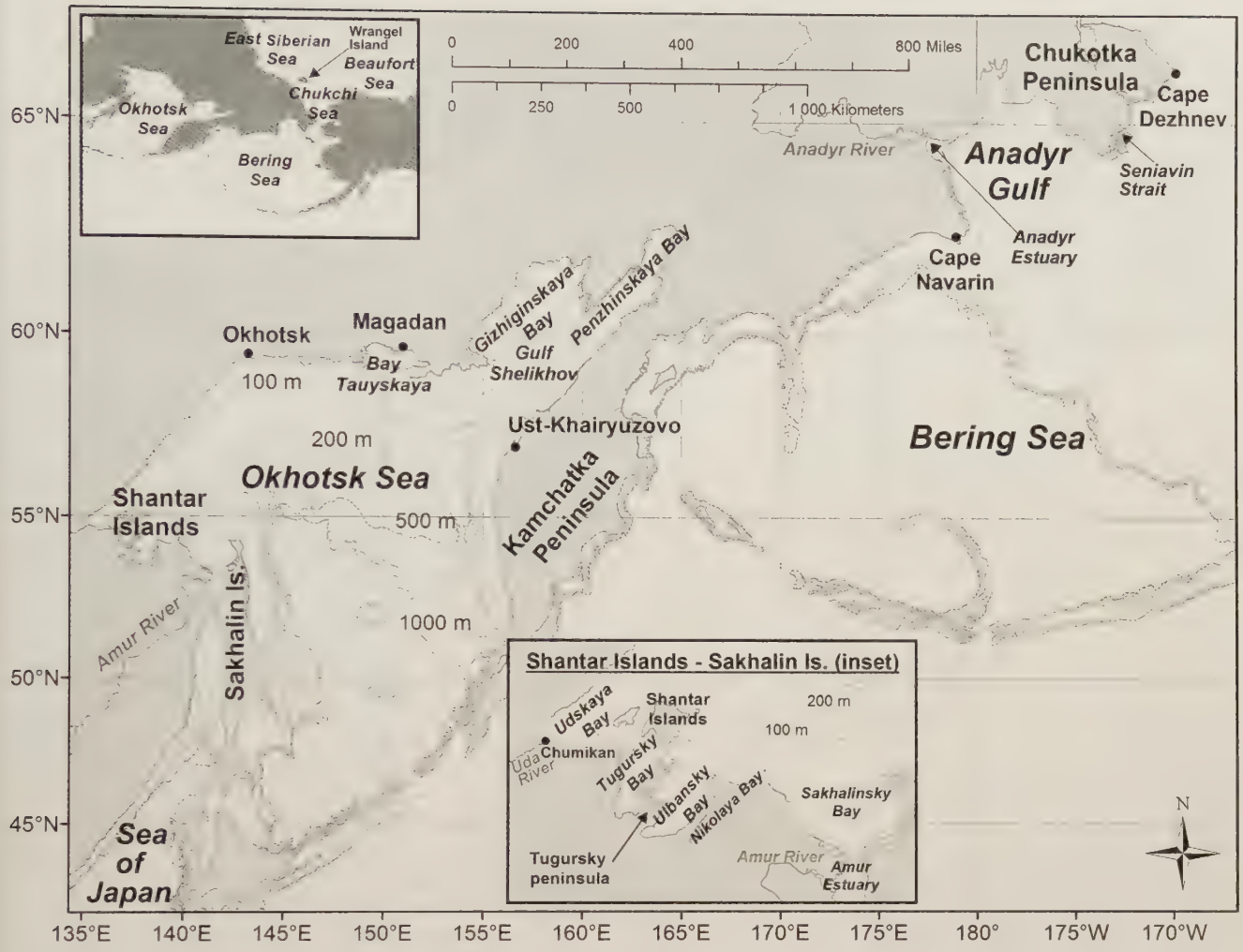

Figure 1.—Russian Far East with toponyms mentioned in the text.

sometimes used in the Russian literature), and small groups, comprised mostly of males, which are more nomadic. A "stock" (also see Hobbs et al., 2019, under "Identification of Stocks"), is a population unit which can be defined as discrete and seasonally stable and should be managed separately from other equivalent units (synonym of "management unit"). Thus, a summer nursery aggregation is considered a stock if its geographical (spatiotemporal) separation from the neighboring aggregations of the same biological population can be proved by genetics, photo-identification, or other methods. Following the guidance in IWC (2000:244), "possible stock units should be split until evidence is available to justify combining them." A "pool" is defined as a large beluga whale unit of an unknown demographic status (presumably made up of multiple stocks or even multiple biological populations), within which we cannot delineate stocks or populations due to the lack of information on their distribution ranges, movement patterns, and genetics.

For the genetic analyses presented herein, we have combined our published (Meschersky et al., 2013, 2018) and unpublished data to delineate each stock, population, or pool. The level of population isolation was evaluated using allele frequencies of 17 microsatellite loci: (Cb1, Cb2, Cb4, Cb5, Cb8, Cb10, Cb11, Cb13, Cb14, Cb16, Cb17 – Buchanan et al., 1996; Ev37Mn, Ev94Mn – Valsecchi and Amos, 1996; 415/416, 417/418, 464/465, 468/469 – Schlötterer et al., 1991; Fullard et al., 2000). The methods of genotyping and sex determination were analogous to those previously described in Meschersky et al. (2013). Sample comparison was performed using the allele frequency based Fst-criterion (Arlequin 3.1 software, Excoffier et al., 2005) and a clustering method (LOCPRIOR-Admixture model, 5 runs of 50,000 MCMC iterations of burn-in and 200,000 iterations of main analysis) using Structure 2.3.4 soft-

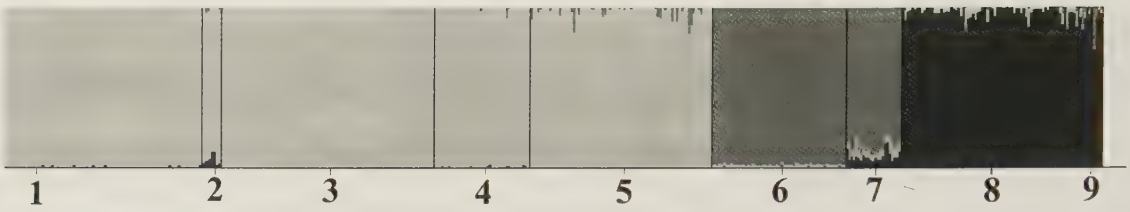

Figure 2.—The results of K = 3 hypothesis tested by clustering analysis based on 17 microsatellite loci alleles frequencies. LOCPRIOR-Admixture model. Samples = 1–Sakhalinsky Bay, 2–Nikolaya Bay, 3–Ulbansky Bay, 4–Tugursky Bay, 5–Udskaya Bay, 6–Western Kamchatka coast, 7–Gizhiginskaya Bay, 8–Anadyr Estuary, and 9–Chukotka coast. Light gray shaded area = western-Okhotsk population, dark gray shaded area = northeast Okhotsk population, and black shaded area = Anadyr-Chukotka pool.

ware (Pritchard et al., 2000). Patterns of spatial distribution within regions and populations were evaluated using maternal lineage (mtDNA haplotypes) distribution (Fst-criterion—haplotypes frequency only, Arlequin 3.1 software). In most cases, a fragment of 559 bp (see Genbank JQ716342, for instance) was used. Where appropriate, results from O'Corry-Crowe et al. (1997) were included to expand the dataset. The original samples (skin biopsies or tissues of dead animals) were collected during the period 2008–16 (and for Sakhalinsky Bay since 2004).

Distribution

Data were collected during aerial and vessel surveys and shore-based operations. Satellite-linked transmitter tags attached to belugas provided additional information on movement patterns and seasonal habitat use. We summarized information from published accounts, technical reports, and unpublished data.

Natural and Anthropogenic Concerns

The Federal Agency of Fisheries provided some numbers for beluga live-captures and traditional hunting. However, due to the obvious incompleteness of reported figures, we also collected information from the regional Fishery offices, and obtained records directly from the companies that captured belugas. Further, we listed major current and potential threats to belugas in different geographic regions based on our expertise.

Results

Okhotsk Sea

Two multi-year projects were conducted in the Okhotsk Sea during the period 2007–16. Genetic analyses (Meschersky et al., 2013), together with geographic distribution studies (Shpak et al., 2010; Solovyev et al., 2015), delineated two biological populations: 1) Western Okhotsk, which includes belugas summering in the Sakhalin-Amur and Shantar regions, and 2) Northeast Okhotsk (or Shelikhov), which spends the summer in the Gizhiginskaya and Penzhinskaya bays of Shelikhov Gulf and along the western coast of the Kamchatka Peninsula (Fig. 1).

Genetic analysis, based on a significantly increased sample (355 samples from the western Okhotsk Sea and 79 from the northeast Okhotsk Sea) compared to the earlier study (Meschersky et al., 2013), confirmed the genetic isolation between these two populations. The Fst distance based on 17 microsatellite loci was estimated at 3.52%. The high level of isolation between the two populations was also confirmed by the clustering method analysis (see samples 1–7, Fig. 2). Maximal average LnP(K) and Delta K (Evanno method, Earl and vonHoldt, 2012) values were found for K = 2 hypothesis for the total Okhotsk Sea sample set. No evidence of further subdivision in the Okhotsk Sea was found for higher K (up to 7) hypotheses. Significant differences (Fst = 32.04%, p = 0.0000) in mitochondrial lineage compositions and frequencies were found between the two Okhotsk Sea regions.

Isolation of the Okhotsk Sea belugas from whales inhabiting the Anadyr Estuary (in the Bering Sea) was demonstrated earlier (Meschersky et al., 2013; Borisova et al.[2]). With the current sample size, we unambiguously confirmed isolation of the Okhotsk Sea belugas from Bering Sea belugas. The combined Anadyr-Chukotka coast sample (n = 83) microsatellite allele distance was estimated at 4.78% for the western Okhotsk population, 4.30% for the Northeast Okhotsk (Shelikhov) population, or 4.15% for the combined Okhotsk Sea sample (n = 434). All pair-wise comparisons were statistically significant (p = 0.0000). The isolation between the Okhotsk Sea and Anadyr-Chukotka belugas was also confirmed by the clustering analysis (Fig. 2).

Western Okhotsk Population

Based on aerial surveys and coastal observations (Solovyev et al., 2015) in the western part of the Okhotsk Sea, belugas concentrate in the shallow waters of the Sakhalin-Amur and Shantar regions in several nursery aggregations during the summer (Fig. 3). Nursery aggregations tend to stay

[2]Borisova, E. A., I. G. Meschersky, O. V. Shpak, D. M. Glazov, D. I. Litovka, and V. V. Rozhnov. 2012. Evaluation of effect of geographical isolation on level of genetic distinctness in beluga whale (*Delphinapterus leucas*) populations in Russian Far East. Marine Mammals of the Holarctic: Collection of papers presented at the 7th Int. Conf., Suzdal, 2012, 1:113–117 (http://marmam.ru/upload/conf-documents/mmc2012_full.pdf).

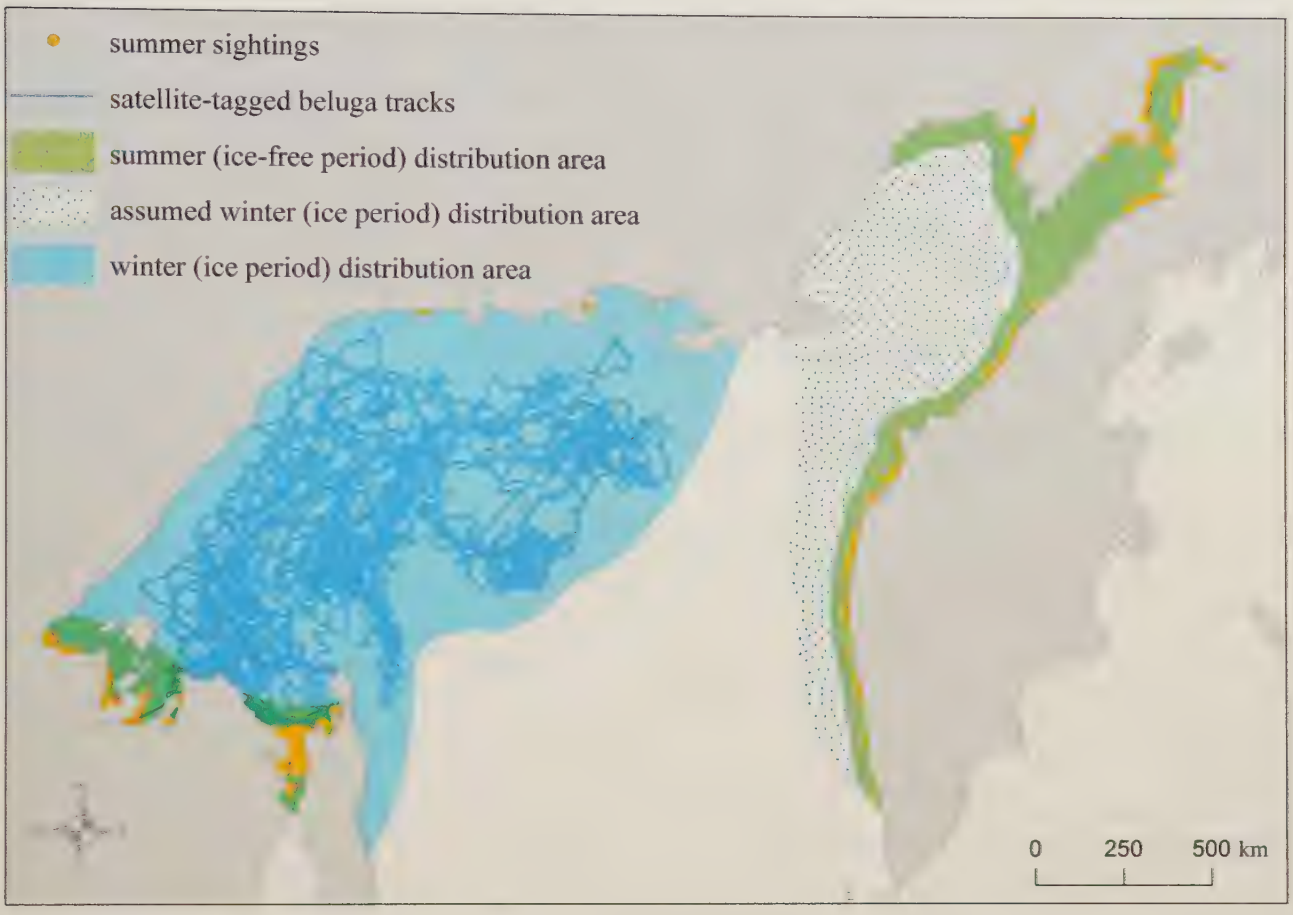

Figure 3.—Okhotsk Sea beluga summer ranges based on aerial surveys, boat and coastal observations during the period 2007–16 (modified and updated from Solovyev et al., 2015), and winter ranges based on satellite tracking data (Shpak et al., 2010; Shpak et al. text footnote 3) for the western Okhotsk population, and on unpublished data for the northeast population.

in the shallower, estuarine areas of the bays, and the lack of sightings at the exits of the bays suggests these aggregations are relatively isolated from each other in summer months. However, two belugas, one with a tag and another—with the scars caused by tagging (apparently, the animals that were tagged in Sakhalinsky Bay in August 2007 and/or July 2008) were photographed in Nikolaya Bay in July 2009 (Shpak and Glazov, 2013). It is unclear whether these belugas moved between the bays within one summer (2009), or, in different years, chose one or the other bay as a summering ground. In September–October, belugas begin to migrate. Some whales travel from Sakhalinsky Bay westward to Nikolaya Bay and may briefly visit Ulbansky Bay as well (Shpak et al., 2010; Shpak et al.[3]). An individual tagged in the middle of September in Ulbansky Bay moved to Nikolaya Bay within a week (Shpak et al.[4]), which led us think we had tagged not an Ulbansky summer resident, but one of Sakhalin-Amur "autumn nomads." A single beluga or small groups, some with immature individuals, are sometimes observed outside areas of major concentration, between the bays or near the Shantar Islands (Solovyev et al., 2015; our unpubl. data; Fig. 3). Similar observations (including mothers with calves) have been reported in the Sea of Japan (Sato and Ichimura, 2011; Melnikov and Seryodkin[5]; our interview data) (Fig. 1), but such cases are rare and thought to be extralimital.

[3]Shpak, O. V., D. M. Glazov, D. M. Kuznetsova, L. M. Mukhametov, and V. V. Rozhnov. 2012. Migratory activity of the Okhotsk Sea belugas *Delphinapterus leucas* in winter-spring period. Marine Mammals of the Holarctic: Collection of papers presented at the 7th Int. Conf., Suzdal, 2012, 2:390–395 (http://marmam.ru/upload/conf-documents/mmc2012_full.pdf).

[4]Shpak, O.V., A. Yu. Paramonov, D. M. Glazov, I. G. Meschersky, and D. M. Kuznetsova. 2018. Results of the pilot project on the beluga whale (*Delphinapterus leucas*) satellite tagging using remote tag deployment without capturing whales. Marine Mammals of the Holarctic: Collection of papers presented at the 9th Int. Conf., Astrakhan, 2016, 2:271–278 (http://marmam.ru/upload/conf-documents/mmc2016_full.pdf).

[5]Melnikov, V. V., and I. V. Seryodkin. 2014. Sightings of beluga whales (*Delphinapterus leucas*) in the Sea of Japan. Materials of the Int. Appl. Sci. Conf.: Habitats, migrations and other movements of animals, Vladivostok, p. 196–198 [in Russ.].

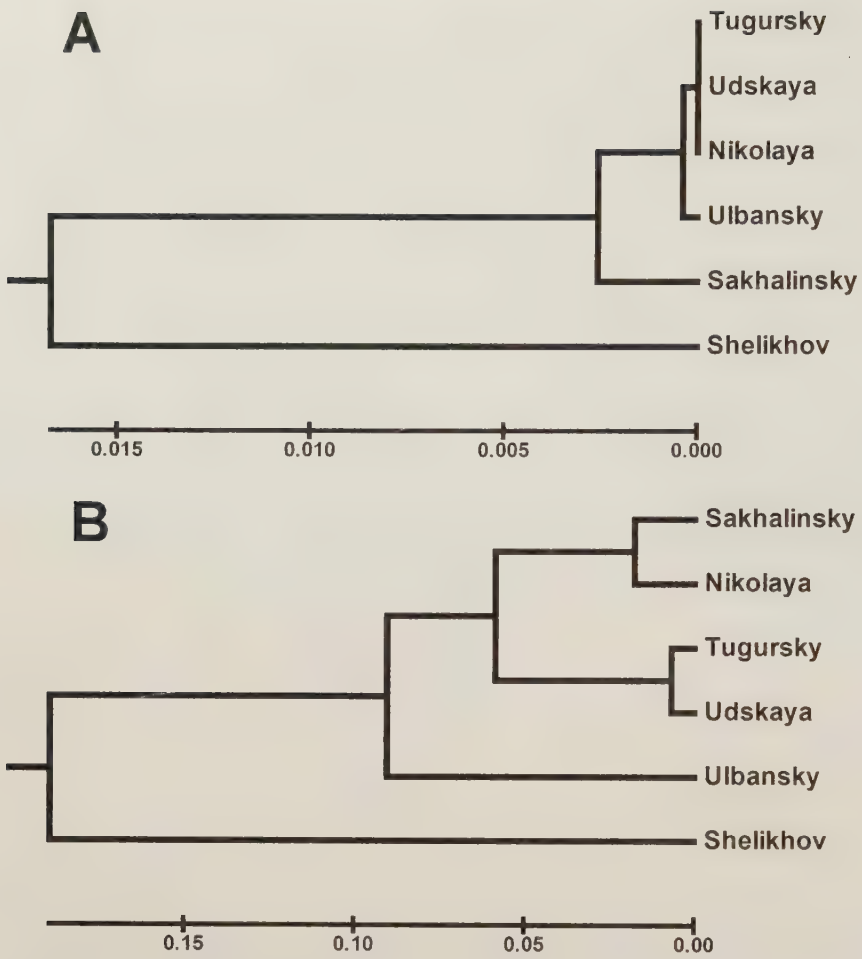

Figure 4.—UPGMA-cladogram of Fst-distances found for beluga whales in the Okhotsk Sea. A) allelic composition of 17 nuclear microsatellite loci, B) presence and frequencies of the mtDNA control region (559 bp) haplotypes.

Russian-Japanese ship-based surveys conducted in July–August 2009–10, primarily in offshore waters of the Okhotsk Sea outside the 12-mile zone, resulted in no sightings of beluga whales (Istomin et al., 2013). This supported past studies and the hypothesis that in summer belugas concentrate in coastal waters and bays (Fig. 3). Data on winter distribution of western Okhotsk belugas is limited to tracking belugas tagged in Sakhalinsky Bay in summer (Fig. 3, Shpak et al., 2010, Shpak et al.[3], Shpak and Glazov[6]). In autumn, Sakhalinsky Bay belugas move offshore north and northeast, but remain in the Okhotsk Sea throughout the year, not entering Shelikhov Gulf or approaching the Kamchatka western coast. Based on one individual tagged in Udskaya Bay (Shpak et al.), it appears these whales stay in the bay, traveling along the coast until December when the bay starts to freeze. We speculate that belugas from Sakhalin-Amur and Udskaya summer aggregations may meet in December–January on the way to wintering grounds.

The most recent abundance aerial surveys in the Okhotsk Sea were conducted in 2009 and 2010 (Shpak and Glazov, 2013; Shpak and Glazov[6]; Glazov et al.[7]). With the exception of the southern part of Sakhalinsky Bay and the Amur Estuary, which were surveyed in parallel line-transects, all other regions were covered with a single-line coastal survey (direct count). At the suggestion of the research team, an availability correction of 50% was accepted by an IUCN expert panel review (Reeves et al.[8]). The abundance estimate for the western Okhotsk population was based on the results from the aerial survey conducted in August 2010. The corrected abundance was 9,560 belugas. Due to differences in survey design across the study area, no coefficient of variation (CV) was calculated.

Genetic analyses showed that all belugas summering in the western Okhotsk Sea shared a single nuclear gene pool and thus represent a single population (Fig. 2). Microsatellite allele frequencies distances between samples collected in different bays of the Shantar region were not significantly different (Fst = 0.00–0.22%, p = 0.0723–0.6984). Belugas of Sakhalinsky Bay differed from other bays (except for Nikolaya Bay) to a greater extent – Fst = 0.41–0.82%, p = 0.0000–0.0020, but these values are incomparably smaller than differences between any sample from the western Okhotsk bays and northeast Okhotsk (Shelikhov) population (Fig. 4A). At the same time, it was shown (see Meschersky et al., 2013) that be-

[6]Shpak, O. V., and D. M. Glazov. 2013. Review of the recent scientific data on the Okhotsk Sea white whale (*Delphinapterus leucas*) population structure and its application to management. Paper SC/65a/SM23 pres. to IWC Sci. Comm., Jeju Island, June 2013, 19 p.

[7]Glazov, D. M., V. I. Chernook, O. V. Shpak, B. A. Solovyev, E. A. Nazarenko, A. N. Vasilev, N. G. Chelintsev, D. M. Kuznetsova, L. M. Mukhametov, and V. V. Rozhnov. 2012. The results of beluga whale (*Delphinapterus leucas*) aerial surveys in the Okhotsk Sea in 2009 and 2010. Marine Mammals of the Holarctic: Collection of papers presented at the 7th Int. Conf., Suzdal, 2012, 1:167–172 (http://marmam.ru/upload/conf-documents/mmc2012_full.pdf).

[8]Reeves, R. R., R. L. Brownell Jr., V. N. Burkanov, M. C. S. Kingsley, L. F. Lowry, and B. L. Taylor. 2011. Sustainability assessment of beluga (*Delphinapterus leucas*) live-capture removals in the Sakhalin–Amur region, Okhotsk Sea, Russia. Rep. of Independ. Sci. Rev. Panel. Occasional Pap. of the SSC, No. 44. IUCN, Gland, Switzerland, 34 p. (http://www.iucn-csg.org/wp-content/uploads/2010/03/Beluga-SSC-Occ-Paper-20111.pdf).

lugas summering in different bays of the western Okhotsk Sea may differ significantly in mitochondrial lineages composition. Analysis based on significantly increased sample sets confirmed these differences (Fig. 4B, Table 1).

Thus, based both on distribution patterns and results of genetic analysis, we propose the following subdivision of the western Okhotsk population into summer stocks.

Sakhalin-Amur Stock. Belugas of Sakhalinsky Bay and the Amur Estuary significantly differ by mitochondrial-lineage composition from other western Okhotsk region bays (with the exception of Nikolaya Bay, see below) and are designated as the Sakhalin-Amur stock. This stock is the largest and best studied of all western Okhotsk summer aggregations. An abundance estimate of the Sakhalin-Amur stock based on three line-transect surveys conducted in 2009 and 2010 was 1,977 (CV = 0.24) belugas. Adding a correction for availability bias (50%) resulted in an overall estimate of 3,954 (CV = 0.24) belugas (Shpak and Glazov, 2013).

During the summer, Nikolaya Bay is occupied with a relatively low number of belugas (usually less than 100), and it is unclear whether this aggregation is seasonally resident or if different groups visit the bay throughout the summer. Belugas of Nikolaya Bay differ by mitochondrial-lineage composition from Ulbansky, Tugursky, and Udskaya bays but not from Sakhalinsky Bay (Fig. 4b; Table 1). These results should be interpreted with caution, however, due to a very small sample size that is skewed towards males from Nikolaya Bay (8 males and 1 female). Nonetheless, further evidence of relatedness between Nikolaya belugas and the Sakhalin-Amur summer stock was obtained from photo-identification studies and behavioral observations. Therefore, until the status of belugas in Nikolaya Bay is confirmed with data of sufficient power, we propose that animals observed in Nikolaya Bay during the summer be assigned to the Sakhalin-Amur stock.

Table 1.—Conventional F-Statistics from haplotype frequencies: Fst (below diagonal) and P (above diagonal) values estimated for belugas of different bays of the western Okhotsk Sea and the Northeast Okhotsk (Shelikhov) population. Bold indicates bays that were not statistically different.

	Sakhalinsky Bay, $n = 183$	Nikolaya Bay, $n = 9$	Ulbansky Bay, $n = 91$	Tugursky Bay, $n = 45$	Udskaya Bay, $n = 88$	Shelikhov popul., $n = 80$
Sakhalinsky Bay		**0.1507**	0.0000	0.0001	0.0000	0.0000
Nikolaya Bay	0.0354		0.0006	0.0180	0.0021	0.0001
Ulbansky Bay	0.1377	0.3106		0.0002	0.0000	0.0000
Tugursky Bay	0.0819	0.1010	0.1130		**0.1263**	0.0000
Udskaya Bay	0.1096	0.1667	0.1606	0.0136		0.0000
Shelikhov popul.	0.3400	0.3947	0.5183	0.3253	0.3149	

Ulbansky Stock. The identity of the Ulbansky beluga summer stock as a separate demographic unit within the western Okhotsk population is based on the multi-year summer and autumn observations in Ulbansky Bay and genetic analysis (Table 1). In September–October, before winter migration, some belugas from Sakhalinsky Bay move to Nikolaya Bay and may also visit Ulbansky Bay, but overall beluga numbers in the inner part of Ulbansky Bay seem to decrease in autumn. Winter migratory routes and feeding grounds are unknown. In August 2010, 1,167 belugas were counted during a direct count aerial survey (Shpak and Glazov, 2013). Abundance, corrected for availability bias, was estimated at 2,334 belugas.

Tugursky Stock. Although genetic testing did not separate belugas found within Tugursky and Udskaya bays (Fig. 4, Table 1), nevertheless, unlike the situation with Nikolaya Bay, we propose the Tugursky belugas as a separate demographic unit within the western Okhotsk population. This designation is supported by historical information and opportunistic observations. During summer, belugas are regularly seen in the southern (estuarine) part of Tugursky Bay and sometimes along the western coast, and no belugas have been observed travelling between Tugursky and Udskaya bays; although, small groups have been reported near the south coast of Big Shantar Island and along the northeast coast of Tugursky Bay. We noted behavior differences (e.g., reaction to boat presence) between beluga groups in Tugursky and Udskaya bays. Winter migratory routes and feeding grounds are unknown. In August 2010, 753 belugas were counted during a direct count aerial survey (Shpak and Glazov, 2013), with a corrected abundance estimate of 1,506 belugas.

Udskaya Stock. Designating the Udskaya summer stock as a separate demographic unit within the western Okhotsk population is based on historical information, multi-year observations of beluga summer aggregations in the bay, and genetic analysis (with the exception of Tugursky Bay, mentioned above). Belugas are present in the estuarine area from June to October and often enter the Uda River. Belugas are also known to concentrate in the estuary of the Torom River, about 40 km east of the Uda mouth. There are no genetic samples from the Torom concentration area, but frequent beluga sightings between the two rivers suggest that all animals belong to the same stock. Upon ice formation in the Uda estuary, belugas move further from the estuary, but remain coastal. Winter migratory routes and feeding grounds are unknown. In August 2010, 1,232 (2,464, corrected for availability bias) belugas were counted during a direct count aerial survey (Shpak and Glazov, 2013).

Northeast Okhotsk (Shelikhov) Population

Recent information on the Shelikhov beluga population is very limited. Most research effort has concentrated on the western coast of the Kamchatka Peninsula. In the Shelikhov Gulf, belugas are known to approach river estuaries during herring, *Clupea pallasii*; smelt, Osmeridae; and salmon, Salmonidae, runs. Larger aggregations were observed in the lower parts of the bays (Solovyev et al., 2015), but overall distribution was more dispersed along the coastline (Fig. 3) than, for

Table 2.—Frequency based Fst distances (%/%) found between each of the two Northeast Okhotsk population sample sets (Kamchatka and Gizhiginskaya) and two regions of the western Okhotsk population (Sakhalinsky Bay/Shantar). All differences were statistically significant at $p = 0.0000$ level.

Marker	Kamchatka	Gizhiginskaya
Alleles of 17 microsat. loci	4.71 / 3.59	4.55 / 3.08
mtDNA haplotypes	31.42 / 31.68	42.22 / 36.50

example, in any of the Shantar region bays. In summer 2016, a large nursery aggregation of over 400 belugas was observed feeding on salmon in the estuarine part of Gizhiginskaya Bay, and smaller groups of up to 20, mostly adults, were encountered along its eastern coast (Filatova et al.[9]), the pattern very much resembling the distribution observed on aerial surveys during the period 2009–2010 (Fig. 3). Beluga form relatively stable summer aggregations within particular river estuaries (e.g., the Khairyuzova, see Ust-Khairyuzovo on Fig. 1) on the central west coast of the Kamchatka Peninsula. Only occasional sightings are reported along the southern west coast. No belugas have been encountered at the south tip or along the east coast of the peninsula (Solovyev et al., 2015).

Very little is known regarding Northeast Okhotsk beluga winter distribution. In the 1980's, belugas were found along the ice edge in Shelikhov Gulf and off western Kamchatka in January–February (Vladimirov and Melnikov, 1987). Fedoseev (1984) encountered belugas in Shelikhov Gulf also in April a satellite-tagged beluga remained in Shelikhov Gulf throughout the winter until April (our unpubl. data). The ice edge extent largely varies from year to year and often stretches south from Shelikhov Gulf. We suppose in such cases, Shelikhov belugas remain near the ice edge or along the west coast of Kamchatka and, when ice conditions allow, they may return to the gulf. During a coastal single-line survey in August 2010, 1,333 belugas were counted and after corrected for availability bias, abundance of the Northeast Okhotsk population was estimated as 2,666 belugas (Shpak and Glazov, 2013).

Reproductive isolation of belugas summering in the northeast part of the Okhotsk Sea, in Shelikhov Gulf and along the west coast of Kamchatka Peninsula, from whales summering in the western Okhotsk Sea was confirmed by genetics studies (Fig. 2, 4). Sightings in Shelikhov Gulf in winter suggest these whales do not overwinter with the western Okhotsk stocks. In our study, sample set "Kamchatka" consisted of 57 individuals (39 males, 15 females, sex of 4 individuals is unknown) biopsied or found dead during the period 2009–12. Whales were from the west coast of the Kamchatka Peninsula ranging from the Khairyuzova estuary ($n = 52$) to the lower part of Penzhinskaya Bay. The sample set "Gizhiginskaya" consisted of 22 biopsy samples (21 males and only one female) collected in 2016 in the Gizhiga River estuary in the north and along the east coast of Gizhiginskaya Bay. Both sample sets differed from the Sakhalinsky Bay and Shantar regions by similarly significant level (Fig. 2; Table 2).

Although summer aerial surveys showed discontinuity in the coastal distribution of belugas between Shelikhov Gulf and western Kamchatka (Solovyev et al., 2015), no strong evidence for delineating the stocks within the Northeast Okhotsk population are available. Differences between the two population sample sets were found to be significant, although at a low level: Fst = 1.46% ($p = 0.0006$) for microsatellites, and Fst = 22.86% ($p = 0.0007$) for mtDNA. However, this may be the result of inadequate sampling. This includes multi-year versus single year collecting, unusual predominance of males, and low mtDNA lineage diversity in the "Gizhiginskaya" sample set (90% of individuals had the same haplotype, H = 0.1775 vs. H = 0.5650 found for "Kamchatka"). Moreover, clustering method analysis showed only minor differences between "Kamchatka" and "Gizhiginskaya" belugas and determined the two sample sets were a single genetic cluster. Future studies will likely find some intrapopulation structuring, but at present all belugas from the Northeast Okhotsk population are considered a single stock (Shelikhov).

Thus, in the Okhotsk Sea, five beluga summer stocks should be designated based on information available to date: Sakhalin-Amur, Ulbansky, Tugursky, Udskaya, and Shelikhov.

We note that the current gap in beluga distribution in the northwest portion of the Okhotsk Sea is a relatively new pattern. Numerous Soviet literature sources state that in the first half of the 20th century, belugas regularly aggregated in Tauyskaya Bay (Fig. 1), but after several years of commercial harvest in early 1930's, they disappeared. The aggregation was either extirpated or abandoned this summer ground. In 2008, two unusual sightings of about 1,500 and 100–150 belugas were reported in Tauyskaya Bay by A.I. Grachev[10]. Apart from these two observations, there were very few encounters of single whales or small groups in the bay. Without genetic data, we are unable to determine which of the two Okhotsk Sea populations may have seasonally occupied Tauyskaya Bay in the early 20th century and during the summer of 2008.

Chukotka Autonomous Region

In Russian waters of the western Bering and western Chukchi seas, belugas occur near Wrangel Island, along the entire coast of the Chukotka Peninsula, in Anadyr Gulf, and, in winter, around Cape Navarin (Fig. 1). Only in Anadyr Gulf, are belugas known to form a summer resident aggregation (Arsenyev, 1939; Kleinenberg et al., 1964). Genetic isolation of Anadyr belugas from the populations of the Okhotsk Sea was shown by Meschersky et al. (2013), but their original stock

[9]Filatova, O. A., O. V. Shpak, A. Ju. Paramonov, D. M. Glazov, A. I. Grachev, and I. G. Meschersky. 2018. Cetacean encounters in the coastal waters of the northern Okhotsk Sea in the summer 2016. Marine Mammals of the Holarctic: Collection of papers presented at the 9th Int. Conf., Astrakhan, 2016, 2:218–222 (http://marmam.ru/upload/conf-documents/mmc2016_full.pdf).

[10]Grachev, A. I. (deceased) MagadanNIRO, Russia, unpubl. data.

designation in 2000 was based mostly on distribution studies within the Bering-Chukchi-Beaufort (BCB) region (IWC, 2000). The status of other belugas observed along Chukotka Peninsula in the Chukchi and Bering seas remains to be confirmed.

In the eastern part of the East Siberian Sea, belugas are rare. Most coastal sightings were near the mouth of the Kolyma River (Kleinenberg et al., 1964). Belikov and Boltunov (2002) mentioned only twelve offshore sightings of belugas during sea ice reconnaissance for the period 1958–1995. Satellite tracking of eastern Beaufort Sea belugas in the 1990's showed a westward autumn migration during which whales travelled as far west as Wrangel Island (Richard et al., 2001). In multiple literature sources, belugas from the BCB region and the East Siberian Sea were either grouped into one population (for ex., Klumov, 1939; Kochnev, 2003; Belikov et al., 2002[11]), or subdivided into multiple stocks or populations (Berzin and Yablokov, 1978; IWC, 2000; and many others), but either delineation lacked sufficient grounding. Until the question of population structure is clarified, we prefer to use the term "pool" for BCB belugas. The following sections summarize Russian studies conducted within this region, supplementing data collected on the other stocks in the BCB pool that have been published in English and that are readily accessible.

Anadyr Stock

Belopol'sky[12] and Pikharev[13] described the movements of belugas into the Anadyr Estuary after ice breakup, and stated that the whales were commonly seen in groups ranging in size from dozens to thousands. In the Anadyr Estuary during the ice-free period, whales concentrated in shallow waters and traveled up to 200 miles into the estuary (Litovka, 2002). Short-term pilot photo-identification study in 2013 revealed few re-sightings within a season (Prasolova et al., 2014). Our observations support a hypothesis that in summer belugas form a resident aggregation in the Anadyr Estuary (Fig. 5). Telemetry studies of Anadyr belugas during the period 2001–10 (Litovka et al., 2013; Citta et al., 2017; Litovka et. al.[14,15]; Hobbs et al.[16]) confirmed and clarified distribution and movement patterns in the Anadyr Estuary and Anadyr Gulf, which had previously been based on coastal and aerial counts (Litovka, 2002).

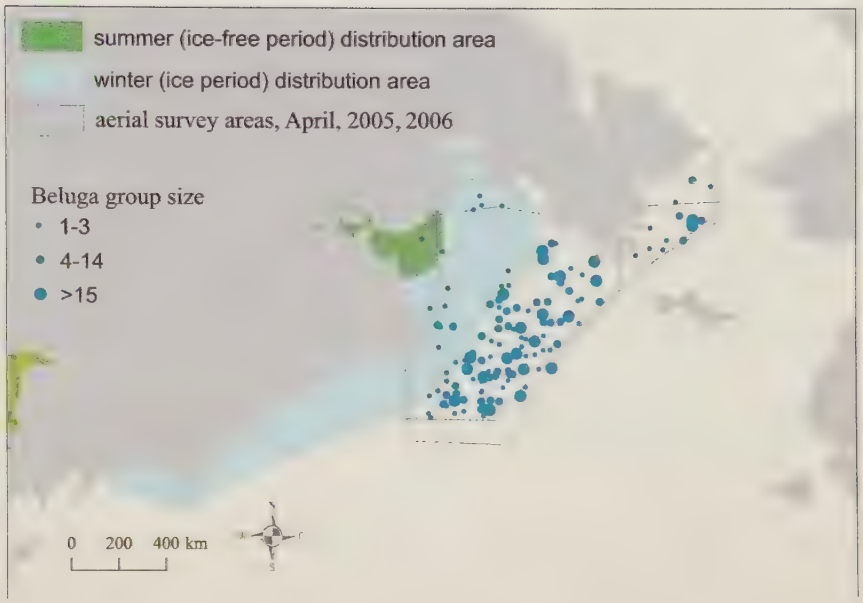

Figure 5.—Summer and winter ranges of Anadyr belugas based on observations and satellite-tracking data from published literature sources (see text) and beluga sightings and group sizes during aerial surveys in April 2005 and 2006 (redrawn from Litovka et al., text footnote 17).

Belugas spend the ice-free period (5–6 months) in the Anadyr Estuary. The latest reported sighting occurred in late November. As ice forms in the estuary, belugas leave the Anadyr River mouth. They move northeast to feed on smelt, and later migrate to the exit and southern part of Anadyr Gulf (Litovka et al., 2013). Results from telemetry studies (Citta et al., 2017; Litovka et al.[14]) and aerial surveys conducted in April (Litovka et al.[17]) suggest Anadyr belugas may mix with other BCB stocks while in feeding areas off Cape Navarin in winter–spring (December–April) (Fig. 5).

No abundance surveys have been conducted in Anadyr Gulf in sum-

[11]Belikov, S. E., A. N. Boltunov, and Yu. A. Gorbunov. 2002. Distribution and migrations of cetaceans in Russian Arctic according to multiyear aerial reconnaissance of sea ice and information from "North Pole" drift station. Marine mammals: Results of research conducted in 1995–1998. Collection of Pap. Moscow: Mar. Mamm. Counc., p. 21–51 [in Russ.].

[12]Belopol'sky, L. O. 1931. Short preliminary report on marine mammals research in Anadyr region. TINRO archive, cat. #25, 25 p. [in Russ.].

[13]Pikharev, G. A. 1943. The beluga whale and pinnipeds in coastal waters of Anadyr region. TINRO archive, cat. #2585, 29 p. [in Russ.].

[14]Litovka, D. I., R. C. Hobbs, K. L. Laidre, G. M. O'Corry-Crowe, J. R. Orr, P. R. Richard, R. S. Suydam, and A. A. Kochnev. 2002. Research of belugas *Delphinapterus leucas* in Anadyr Gulf (Chukotka) using satellite telemetry. Marine Mammals of Holarctic: Abstracts of The 2nd Int. Conf., Lake of Baikal, 2002, p. 161–163 (http://marmam.ru/upload/conf-documents/mmc2002_full.pdf).

[15]Litovka, D. I., R. C. Hobbs, K. L. Laidre, G. M. O'Corry-Crowe, J. R. Orr, P. R. Richard, and R. S. Suydam. 2004. Studying of dive patterns of belugas (*Delphinapterus leucas*) in Anadyr-Navarin region of Bering Sea using satellite telemetry. Marine Mammals of Holarctic: Collection of papers presented at the 3rd Int. Conf., Koktebel', Ukraine, 2004, p. 327–331 (avail. at http://marmam.ru/upload/conf-documents/mmc2004_full.pdf).

[16]Hobbs, R. C., D. I. Litovka, and G. M. O'Corry-Crowe. 2007. Bering Sea wintering grounds of beluga whales. Seattle, WA. N. Pac. Res. Board Final Rep. 324:1–12

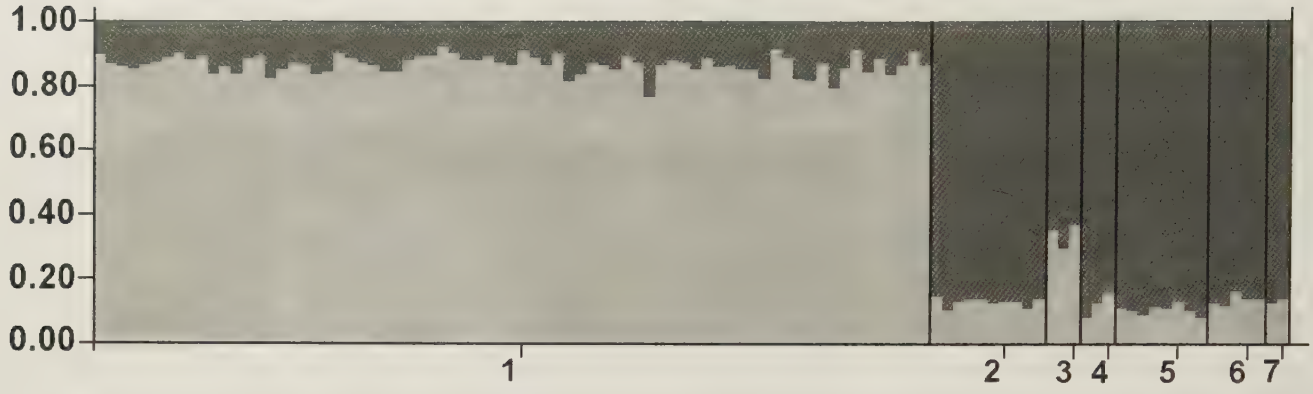

Figure 6.—Results of K = 2 hypothesis (most probable solution) tested by LOCPRIOR-Admixture model for allele frequencies of 17 microsatellite loci. 1 – Anadyr Estuary, 2 – Chukotka Peninsula coast, 3 – Beaufort Sea, 4 – Diomede Isl., 5– Eastern Chukchi Sea, 6 – Norton Sound, 7 – Bristol Bay.

mer. Coastal observations suggest two peaks in sighting rates: 1) from the end of June to the beginning of July, and 2) in the beginning of August, both of which coincide with salmon spawning. The largest concentration, 241 whales, was recorded in late June (Litovka, 2002). Pacific walrus, *Odobenus rosmarus*, aerial surveys with opportunistic beluga counts were conducted in April 2005 and 2006 (Fig. 5). The surveys did not cover the area south of Cape Navarin, where, according to satellite tracking data, part of the Anadyr beluga stock may have resided. In April 2005, 162 groups of 410 whales total were counted, and in April 2006, 195 groups with 403 individuals total (Litovka et al.[17]). The estimated beluga abundance using a correction for availability (2.86) was 15,127 (7,447–30,741) (Litovka[18]). This estimate represents "a theoretical abundance calculated as direct extrapolation of the estimated mean density to the unsurveyed areas" (Litovka[18]) and should be viewed with caution. In addition, some of the beluga whales observed in April may have belonged to one or several BCB region stocks given their overlap in winter–spring range. An estimate of the Anadyr summer stock of about 3,000 belugas (Litovka, 2002) appears more realistic and should be used for management purposes until a dedicated survey of the summering area is conducted.

Meschersky et al. (2013) show that some Anadyr belugas possess mitochondrial haplotypes phylogenetically different from those of maternal lines common elsewhere in the BCB region. The differences observed in the Anadyr sample set (n = 76) from other BCB stocks, when compared to data from O'Corry-Crowe et al. (1997), are strong, although with varying degrees of significance. For the Beaufort Sea sample (n = 96) the Fst = 4.48% (p = 0.0011), while for the eastern Chukchi Sea (n = 113) and Norton Sound samples (n = 74) the Fst = 31.4%–44.0% (p = 0.0000), respectively. These results, together with data on distribution, support delineation of Anadyr Gulf belugas as a separate stock.

We also conducted analysis of 17 microsatellite loci for the above mentioned Anadyr Estuary sample, a sample from the Chukotka Peninsula coast (n = 10), and samples from other stocks in the BCB region (provided by the Mammal Genomic Resources Collection, Univ. of Alaska Museum of the North (UAM)). These included three samples from the Beaufort Sea (UAM:Mamm: 76608, 86886, and one sample from A. N. Severtsov Institute collection), eight samples from the eastern Chukchi Sea (UAM:Mamm: 52221–25, 70322–24, 70326), three samples from the Diomede islands (UAM:Mamm: 66416, 98081–82), five samples from Norton Sound (UAM:Mamm: 70519–20, 70522–23, 70525), and two samples from Bristol Bay (UAM:Mamm 66633, 83385). Although, the Anadyr sample was not significantly different from the Chukotka Peninsula and eastern Chukchi Sea samples (n > 5) (Fst = 0.97%, p = 0.0692 and 0.86%, p = 0.12474, respectively), a cluster analysis of the entire BCB sample suggests two clusters, one represented by Anadyr belugas (Fig. 6).

O'Corry-Crowe et al. (2018) also obtained similar results showing: 1) substantial mtDNA differences between Anadyr and five other major summer coastal concentration areas within the BCB region (Bristol Bay, Norton Sound, Kotzebue Sound, Kasegaluk Lagoon, Mackenzie-Amundsen); 2) few differences in allelic composition of eight microsatellite loci; and 3) moderate differentiation of Anadyr belugas revealed by clustering analysis. These authors also concluded that the belugas of the Anadyr summering aggregation should be defined

[17]Litovka, D. I. , V. I. Chernook, A. A. Kochnev, A. N. Vasiliev, A. V. Kudriavtsev, and V. G. Myasnikov. 2006. Distribution of beluga (*Delphinapterus leucas*) and bowhead (*Balaena mysticetus*) whales in the northwestern Bering Sea according to aerial survey performed in April, 2005 and 2006. Marine Mammals of Holarctic: Collection of papers presented at the 4th Int. Conf., Saint-Petersburg, 2006, p. 323–327 (http://marmam.ru/upload/conf-documents/mmc2006_full.pdf).

[18]Litovka, D. I. 2013. Ecology of Anadyr stock of the beluga whale *Delphinapterus leucas* (Pallas, 1778). Ph.D. Dissert., Voronezh State Univ., Voronezh, Russia, 149 p. [in Russ.].

as a separate stock. Mixing of Anadyr belugas with other BCB stocks, if it exists, is more likely to occur with the eastern Beaufort Sea belugas. This hypothesis is supported both with satellite tracking data (Citta et al., 2017), which showed that Beaufort belugas migrate closer to Chukotka Peninsula and Anadyr Gulf than the other stocks, and comparatively lower genetic differences between Anadyr and eastern Beaufort Sea samples (Fig. 6).

Bering-Chukchi-Beaufort Pool

In summer, beluga sightings along the Chukotka Peninsula are relatively rare. It is not until autumn that most whales concentrate in the western Chukchi Sea, and winter and early spring in the Bering Strait and western Bering Sea. The sightings in the eastern part of the East Siberian Sea are rare, and most occurred during the period September–October (Kochnev, 2003; Belikov et al.[11]). The most recent (late September 2002) westernmost sighting of "many" belugas (at about lat. 69.75° N, long. 164.1° E) was provided to Kochnev (2003) by local hunters. This timing coincides with results from satellite-tracked belugas from the eastern Beaufort Sea stock (Richard et al., 2001; Hauser et al., 2014), that in autumn moved across the Chukchi Sea to the East Siberian Sea, some approaching Chukotka while others remained offshore (around Wrangel Island). Kochnev (personal commun.) noted that such approaches were irregular and may be linked to the ice conditions: for example, they were frequent in the 1950's–1960's, but not again until the 1990's. Belugas may enter the East Siberian Sea from the Chukchi Sea by following the mainland coastline, or approach from the north (Arctic Ocean), the latter route is supported by observations and tracking data (Richard et al., 2001; Hauser et al., 2014; Melnikov, 2014; Belikov et al.[11]).

Solovyev et al. (2013) created a good representative picture of beluga seasonal distribution and numbers based on the coastal observations from twelve villages along Chukotka Peninsula's northern, eastern, and southern coasts. The presence of belugas was low in June, July, and August. Kochnev (2003) also noted the lack of large numbers of belugas summering in the western Chukchi Sea, along the northern coast of the Chukotka Peninsula, and the waters around Wrangel Island. According to Kochnev (2003), belugas are absent near Wrangel Island in summer, and along the northern coast of the peninsula most of the year, except for autumn. The lack of a historic traditional beluga harvest to the west of long. 172°W further supports this observation (Kochnev, 2003; Bogoslovskaya and Krupnik[19]). Melnikov (2014) also states that in summer belugas are rarely observed along the Chukotka coast, both in Chukchi and Bering seas.

From all reviewed sources it is clear that most beluga sightings in terms of frequency and number occur during the spring and autumn migrations. According to Melnikov (2014), spring migration along the southern and eastern peninsula coasts starts in April, and most observations suggest that belugas approach the southeast of the peninsula from the Bering Sea rather than from Anadyr Gulf. These observations correspond well with the satellite tracking analysis (Citta et al., 2017). It is important to note that most of the data in Solovyev et al. (2013) and Melnikov (2014) were collected not by the authors personally but by "Beringia" National Park local employees and hired local residents. Although the remoteness of the study area and lack of comprehensive research make such data invaluable, they should be treated with caution, and cross-checking of information should be applied whenever possible. In addition, Melnikov (2014) does not always cite the sources of the data used in the text and figures.

Whether belugas can winter in the Chukchi Sea in the leads and polynyas is unknown, and different opinions have been expressed. Solovyev et al. (2013) acknowledges this possibility by noting a lack of "the high level of herding" as a sign of "migration activity" (cited from Matishov and Ognetov, 2006) along the northern coast of the peninsula in late autumn, and the rapid emergence of belugas following the Arctic cod, *Boreogadus saida,* in open water areas in winter months. In contrast, Kochnev (2003) and Melnikov[20] do not support this idea, and Kochnev (2003) specifically notes that from December to June belugas are absent along the northern coast of the Chukotka Peninsula. Sightings are limited to the northwest cape of the mainland—Cape Dezhnev (Fig. 1). During autumn months, the home range of eastern Beaufort Sea belugas also shifts from north of Wrangel Island toward the Bering Strait (Hauser et al., 2014).

There are no abundance estimates for belugas approaching the Chukotka Peninsula in different seasons, except for the counts by local observers (Solovyev et al., 2013) and opportunistic counts in the mouth of Anadyr Gulf during the walrus aerial surveys in 2005–06 (see Anadyr Stock section). Meschersky et al. (2018), when comparing the belugas taken in autumn and winter in different parts of Chukotka Peninsula (n = 10) with the data provided by O'Corry-Crowe et al. (1997), found that the mtDNA haplotype composition of the Chukotka sample was significantly different from the eastern Chukchi Sea and Norton Sound samples, but that it did not differ from the Beaufort Sea sample. No differences (Fst = 0.89%, p = 0.2747) in haplotype composition were found between our Chukotka Peninsula and Anadyr samples. Also, the Chukotka Peninsula sample microsatellite allele frequencies did not differ either from Anadyr

[19]Bogoslovskaya, L. S., and I. I. Krupnik. 2000. Aboriginal harvest of the beluga whale in the Far East. Marine Mammals of Holarctic: Collection of scientific papers presented at the Int. Conf., Arkhangelsk, 2000, p. 34–36 [In Russ.] (http://marmam.ru/upload/conf-documents/mmc2000_full.pdf).

[20]Melnikov, V. V. 2012. Cetaceans (*Cetacea*) of the Pacific sector of the Arctic: modern distribution, migrations, abundance. Doctor of Biol. Sci. Dissert. V. I. Ilyichov Pacific Oceanol. Inst., Vladivostok, 305 p. [In Russ.].

Table 3.—The annual beluga Total Allowed Takes (TAT) for North-Okhotsk/West Kamchatka subzones, and summary data for actual permanent removals by live-capture (LC, no. of whales) from Sakhalinsky Bay, North-Okhotsk subzone (from Shpak and Glazov text footnotes 6, 21). Supplemented with information received from the Federal Government-Financed Institution Centre of Fishery Monitoring and Communications (CFMC) for the years 2000, 2014, and 2015.

Year	2000	2001	2002	2003	2004	2005	2006
TAT	n/a	n/a	n/a	n/a	n/a	n/a	1000/0
LC	10 (16[1])	22	10	26	25	31	20
Year	2007	2008	2009	2010	2011	2012	2013
TAT	400/400	100/100	300/300	300/300	150/150	360/50	360/50
LC	0	25	24	30	33	44	81[2]
Year	2014	2015	2016	2017	2018		
TAT	150/0	150/25	0/0	150/25	150/25		
LC	8	21	0	0	n/a		

[1]According to the CFMC, all belugas taken in 2000 were landed under commercial harvest quota, while our data represent live capture numbers. Thus, in total, 26 belugas may have been taken in 2000.
[2]The number reported (Shpak and Glazov text footnote 21) was estimated based on direct observations and reports by capture teams. To compare, the beluga take for 2013 reported to the CFMC was eight whales.

or eastern Chukchi Sea samples (Fst = 0.97%, p = 0.0692, and Fst = 0.00%; p = 0.7614, respectively). Nonetheless, according to the results of the clustering analysis (Fig. 6), Chukotka Peninsula belugas do not belong to the Anadyr cluster.

In their recent study, O'Corry-Crowe et al. (2018) also analyzed 10 beluga samples from the Chukotka Peninsula described as northbound spring migrants and obtained similar results. For the mtDNA, the animals from Chukotka differed from all other BCB sample sets except the Mackenzie-Amundsen whales (eastern Beaufort Sea). No statistically significant differences were found for microsatellite loci alleles, but according to different methods of the assignment testing, Chukotka belugas were assigned to the Beaufort Sea and not to the eastern Chukchi Sea. In summary, no definitive conclusions can be made regarding the status of belugas migrating along the Chukotka Peninsula. Therefore, we recommend they continue to be classified as part of the Bering-Chukchi-Beaufort pool for management purposes in Russia, until larger samples are obtained that suggest otherwise.

Anthropogenic and Natural Concerns

Hunting and Live Captures

Total Allowed Takes (TAT) of aquatic biological resources, including marine mammals, are issued annually in autumn by the Ministry of Agriculture and reflect the maximal theoretically sustainable yield. These documents are publicly available. Corrections and changes may be provided to the issued yields of TAT's if they comply with all necessary legal procedures. The number of licenses requested for traditional harvests or live-captures may be obtained from the Federal Agency of Fisheries, but the actual capture numbers of marine mammals (at least, beluga whales), to our experience, are not reported properly by licensees or regional fisheries offices.

Okhotsk Sea. Until recently, beluga stock structure in the Okhotsk Sea has not been taken into account in the process of calculating TAT's, which in the Russian Federation are distributed across fishing zones and subzones, whether the latter coincide with stock boundaries or not. Shpak and Glazov (2013) presented abundance estimates and recommended to use PBR with a recovery factor (F) from 0.5 to 0.65 for beluga summer stocks of the western Okhotsk population, and to minimize beluga takes (limit them to traditional harvests and scientific takes) in the northeast part of the sea until more data on the Shelikhov population are available. The PBR of 42 (F = 0.65) was suggested for the Sakhalin-Amur stock with a note that, depending on the actual 2013 take, PBR may have to be recalculated with F=0.5. It was also recommended that no takes should be allowed in the little-studied Nikolaya Bay. These recommendations were partly implemented. Starting in 2017, The Ministry of Agriculture recommended distributing the TAT in the Okhotsk Sea among different summer aggregations/regions as follows: in the North Okhotsk fishing subzone, Sakhalinsky Bay and Amur Estuary – 40, Nikolaya and Ulbansky bays – 40, Tugursky Bay – 20, Udskaya Bay – 40, northern coast – 10; and in the West Kamchatka subzone, Gizhiginskaya Bay – 7, Penzhinskaya Bay – 6, and West Kamchatka coast – 12. We have compiled information on beluga live-captures in the Okhotsk Sea starting in 2000 (Table 3).

All beluga captures (Table 3) in the North Okhotsk subzone were conducted in southern Sakhalinsky Bay and, possibly in Nikolaya Bay in 2014 and 2015. Boltnev et al. (2016) mentions that on average, live-captures of Sakhalin-Amur belugas do not exceed 30 whales annually, but that the maximum take was "over 100 animals." It is unclear if the authors were provided information unavailable to us, or if they summed the numbers of belugas captured and drowned in 2013 that were provided in Shpak and Glazov[21]. The majority, if not all, live-captured belugas are immature two- to three-year old individuals. Usually, the preferred sex for takes is female.

Quotas for beluga harvest are seldom requested. A quota for traditional hunting of 90 belugas in the North Okhotsk subzone was issued in 2012, but no whales were harvested under this permit (Shpak and Glazov, 2013). To our knowledge, no belugas in the Okhotsk Sea have been landed under traditional harvest quota since 2000. Based on interviews with local people in the Shantar region (where three settlements are located) "several" belugas per settlement are harvested without permit annually. Most people reported beluga meat was used to feed dogs in the winter, and in one village, to be

[21]Shpak, O. V., and D. M. Glazov. 2014. Update report on the white whale (*Delphinapterus leucas*) live captures in the Okhotsk Sea, Russia. Paper SC/65b/SM14 pres. to IWC Sci. Comm., Bled, Slovenia, May 2014, 4 p.

Table 4.—The annual beluga Total Allowed Takes (TAT) for Chukotka Autonomous Region and total actual landings in each of the four Chukotka fishing zones, 2000–16 (from Boltnev et al., 2016, updated by D. Litovka); harvest data in 2003 was provided by the CFMC.

Year	TAT	WBSZ[1]	CFZ[2]	CSFZ[3]	ESSFZ[4]	Total take
2000	200	2	0	4	0	6
2001	200	3	0	4	0	7
2002	200	1	3	2	0	6
2003	200	?	?	?	?	22
2004	200	12	2	12	0	26
2005	200	10	0	10	0	20
2006	200	1	1	0	0	2
2007	200	0	3	0	0	3
2008	200	0	6	2	0	8
2009	200	0	50	0	0	50
2010	200	0	8	0	0	8
2011	200	0	0	0	0	0
2012	200	1	9	8	0	18
2013	200	0	11	3	0	14
2014	200	0	0	0	0	0
2015	200	0	3	0	0	3
2016	200	0	2	0	0	2
2017	200	0	2	8	0	10
2018	200	0	1	4	0	5[5]

[1]WBSZ - Western Bering Sea Fisheries Zone (from Koryak coast to long. 175°W).
[2]CFZ - Chukotskaya Fisheries Zone (from long. 175°W to Cape Dezhnev).
[3]CSFZ - Chukchi Sea Fisheries Zone (from Cape Dezhnev to Longa Strait).
[4]ESSFZ - East-Siberian Sea Fisheries Zone (from Longa Strait to the Kolyma River).
[5]Incomplete data, only spring take is included.

consumed by people. In the Sakhalin-Amur region, we did not hear about harvesting belugas for food, but there was mention of several cases of fishermen shooting beluga when the whales entered salmon traps or approached nets. We do not have any information from Shelikhov Gulf and western Kamchatka. Bogoslovskaya and Krupnik[19] relied on information from an ethnographer, who reported that beluga takes in this region were "occasional" and did not exceed 10 whales per year. Human-caused beluga incidental mortality, as bycatch in salmon traps, gillnets, and poachers' sturgeon nets, and ship-strikes, cannot be estimated. We are aware of several cases of beluga bycatch in the Sakhalin-Amur and Shantar regions. Ship strikes were not recorded or reported.

Chukotka Autonomous Region. The beluga harvest during 1915–98 for Chukotka was summarized by Bogoslovskaya et al. (2007). For the 65 years analyzed, an average of 34.2 (SE = 6.3, median = 18) belugas were taken annually, and only twice (in 1925 and 1950) did the harvest exceed currently set TAT (200 belugas). Although the authors mentioned lack of catch data from one of the villages for many years, the data in general reflect beluga takes in the Soviet Union period.

In recent decades, TAT's for Chukotka waters have been calculated as the abundance estimate multiplied by a theoretical growth rate of 4% and precaution coefficient of 0.5 due to the absence of sufficient data on beluga abundance and population parameters. Abundance estimates of 10,000 belugas for the western Bering Sea and 4,000 whales for the western Chukchi Sea (Vladimirov, 1994) have been used for these TAT calculations. These estimates were based on different sources and should be considered as an "expert opinion." In the absence of exact figures and given possible errors, the abundance of 10,000 belugas (Boltnev et al., 2016 based on Vladimirov, 1994) was used, and the TAT for Chukotka waters was set to 200 whales (Table 4).

Based on the data presented above, we recommend the Anadyr beluga stock be managed separately. Due to the lack of information on BCB pool stock structure and movement patterns, belugas from the BCB pool in Chukotka waters (Bering Sea, Chukchi Sea, East Siberian Sea) cannot be further subdivided into management units. Until more data are available, we recommend management of the BCB pool as a single stock and maintaining the currently used distribution of the TAT across the four fishing zones (Table 4).

For the entire Chukotka region, Native hunters harvested 205 belugas during the period 2000–17, or, on average, a little over 11 animals per year. Apart from 2003, for which no breakdown is available, the majority (83%) of whales were harvested in the Bering Strait area (CFZ) and along the Arctic coast of the Chukotka Peninsula (CSFZ). Belugas were taken only during the spring and fall migrations. The beluga harvest significantly decreased after the Chukotka Native harvest began including larger species of whales (bowhead whales, *Balaena mysticetus,* and gray whales, *Eschrichtius robustus*) and walruses from 2008–10.

The illegal harvest of belugas in Chukotka is considered insignificantly small. Beluga hunting requires Native skin boats, special skills and equipment; however, no more than 25% of marine mammal hunters possess them. According to other sources, in 2006, Chukotka hunters landed 13 belugas, and none were taken in 2007 (Zdor and Mymrin[22]). In 2009, according to the same authors, six belugas were landed in the region (Mymrin and Zdor[23]). These numbers do not coincide with the numbers available to us (Table 4). Despite the differences in the numbers of landed whales, it is clear that beluga harvest in Chukotka is far below the TAT set by the Russian Ministry of Agriculture.

Not included in the numbers presented above are the whales harvested during ice entrapments. In Chukotka, belugas sometimes become entrapped in ice in Seniavin Strait (Fig. 7). The most dramatic occasion happened in December 1984 when about 3,000

[22]Zdor, E. V., and N. I. Mymrin. 2008. Results of marine mammals hunting in Chukotka in 2006–2007 and environment notes. Marine Mammals of Holarctic: Collection of papers of the 5th Int. Conf., Odessa, Ukraine, p. 617–619 (http://marmam.ru/upload/conf-documents/mmc2008_full.pdf).

[23]Mymrin, N. I., and E. V. Zdor. 2010. Results of the marine mammals harvest in Chukotka in 2009. Marine Mammals of Holarctic: Collection of papers presented at the 6th Int. Conf., Kaliningrad, p. 412–415 (http://marmam.ru/upload/conf-documents/mm%D1%812010_full.pdf).

Figure 7.—Belugas entrapped in ice in Seniavin Strait (photo provided by I. Zagrebin).

whales became entrapped. Mymrin[24] described the entrapment and actions taken by locals and authorities from 13 December when a local hunter first spotted belugas, until 5 June when a few belugas were seen for the last time. Over 500 individuals from the entrapped aggregation were harvested by locals during that winter.

Another instance of beluga ice entrapment in Seniavin Strait took place in December 2011. Approximately 100 whales spent the winter in polynyas in Seniavin Strait, and most (if not all of them) died (Zagrebin[25]). On 12 January 2012 (Fig. 7), seven belugas were harvested, and one was found dead. All harvested whales had empty stomachs. The next month, two whales were found dead and three were taken. Several belugas still remained trapped in early April.

Other Potential Threats

Social and industrial development (fisheries, gold mining and ore transport, oil and gas exploration and production) in the Far East, together with climate change, pose new threats to belugas, who closely associate with ice in winter and demonstrate a high site-fidelity to coastal waters and shallow estuarine parts of the bays in summer. These arising challenges to the species need be considered when managing the stocks. The Sakhalin-Amur, Tugursky, Udskaya, and Shelikhov stocks were commercially harvested in the Soviet Union (mostly before the 1950's). Information on harvest and original abundances is limited, and it is difficult to assess whether all stocks have completely recovered. The Anadyr stock has never been overharvested and is considered stable. Sakhalinsky Bay and Amur Estuary as well as Anadyr Gulf are areas intensively exploited by salmon fisheries. This type of industry has also developed in all of the bays of the Chukotka and Shantar regions. Belugas compete with fishermen, and enter salmon traps causing conflicts. The current salmon catch (together with illegal operations) is likely decreasing the carrying capacity, at least, in Sakhalinsky Bay. We do not have information on the intensity of salmon fisheries in the Shelikhov region.

Amur River flooding, leading to washing of human/pet/livestock waste and chemicals into the estuaries, is also of concern. Alekseev et al. (2017) showed that, after a catastrophic flood in 2013, the health of belugas was affected by infectious and invasive diseases, whose causative agents were associated with terrestrial animals. Flooding in the populated flat-coast lower parts of Uda and Anadyr river estuaries is also of similar concern. The gold-mining industry is highly developed across the entire Okhotsk Sea coast with the potential threat of river and estuarine pollution by toxic substances. Ship strikes have not been reported, but direct disturbance and noise should be considered as threats in, at least, the Sakhalin-Amur area, Udskaya Bay, Anadyr Estuary, and Bering Strait. Future climate change and sea ice reduction will extend the

[24]Mymrin, N. I. 2006. Beluga whales (*Delphinapterus leucas P.*) in the ice trap. Bering Strait, Chukotka. Marine Mammals of Holarctic: Collection of papers presented at the 4th Int. Conf., Saint- Petersburg, 2006, p. 377–380 (http://marmam.ru/upload/conf-documents/mmc2006_full.pdf).

[25]Zagrebin, I. A. 2012. The beluga whales (*Delphinapterus leucas* Pallas) in the Senyavina strait: again in ice trap. Marine Mammals of Holarctic: Collection of papers of the 7th Int. Conf., Suzdal, 1:254–257 (http://marmam.ru/upload/conf-documents/mmc2012_full.pdf).

period of open water and increase the flow of marine traffic in the Bering Strait. Whether this will affect belugas is unknown, since their migration routes and timing may also change. It is also anticipated that seismic and military activities in the BCB region, including the eastern part of the East Siberian Sea, will increase with longer ice-free periods.

Conclusions

Revised assessment of beluga abundance, distribution, and population structure in the Russian Far East led to us recognizing seven beluga stocks, five stocks in the Okhotsk Sea: 1) Sakhalin-Amur, 2) Ulbansky, 3) Tugursky, 4) Udskaya, 5) Shelikhov, and two stocks in the Chukotka Autonomous region waters: 6) Anadyr and 7) Bering-Chukchi-Beaufort (BCB) pool. These new designations will help improve management of these stocks when addressing concerns about natural and anthropogenic threats.

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Patterns of mtDNA Variation in Relation to Currently Recognized Stocks of Beluga Whales, *Delphinapterus leucas*

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Introduction

Belugas (also known as white whales, *Delphinapterus leucas*) have a discontinuous circumpolar distribution and are one of only two toothed whale species found in the Arctic year round (O'Corry-Crowe, 2018). Belugas can migrate over vast distances—thousands of kilometres in some regions—between summering grounds (where they aggregate in shallow bays) and deeper wintering areas where they stay close to the sea ice fringe (Heide-Jørgensen et al., 2010; Citta et al., 2017). The size of beluga stocks differs markedly, from tens of thousands of individuals in western Hudson Bay and eastern Beaufort Sea to only hundreds in Cook Inlet, Svalbard, and St. Lawrence Estuary (Vacquié-Garcia et al., 2020; DFO[1]; Shelden and Wade[2]).

The Global Review of Monodontids (GROM) status review recently recognized 21 beluga stocks in addition to one extirpated stock in southwest Greenland, largely defined as separate summer aggregation sites across the species range (Hobbs et al., 2019). The GROM meeting took place in March 2017, and was the first of its kind in almost two decades. There, beluga researchers and stakeholders convened and combined data from telemetry, aerial surveys, traditional knowledge, and genetics to estimate the number of distinct beluga stocks. Based on the available information, the GROM panel reevaluated each previously recognized stock, in some cases merging old or recognizing new stocks. The previous GROM meeting in 1999 only included a review of Atlantic stocks, and in contrast to the 2017 meeting also included a review of wintering and mixed aggregations (NAMMCO[3]). The International Whaling Commission (IWC) has also published reviews of beluga stocks in 1993 and 2000, recognizing 16 and 29 stocks, respectively (IWC, 1993, 2000), while a more recent review recognized 19 stocks (Laidre et al., 2015). This clearly illustrates that although belugas have been studied for decades, delimiting stocks is not straightforward.

Technological advances in the field of genetics during the 1990's was readily adopted in beluga research to address questions regarding stock subdivision and connectivity. Several methodologies have been applied, including DNA fingerprinting (Patenaude et al., 1994), variation in the major histocompatibility complex locus DQβ (Murray, 1997), and restriction fragment length polymorphism (RFLP) (Brennin et al., 1997). The majority of studies published over the past two decades have analyzed regions of the maternally inherited mtDNA control region and microsatellites (Fig. 1, Table 1).

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[2]Shelden, K. E. W., and P. R. Wade (Editors). 2019. Aerial surveys, distribution, abundance, and trend of belugas (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2018. AFSC Processed Rep. 2019-09, 93 p.

[3]NAMMCO. 1999. Scientific committee working group on the population status of beluga and narwhal in the North Atlantic, 36 p. (Avail. at http://nammco.wpengine.com/wp-content/uploads/2016/09/SC_7_4-WG-Report-1999.pdf).

ABSTRACT—Belugas, Delphinapterus leucas, *are one of only three whale species endemic to Arctic and sub-Arctic seas. They are found in both the Atlantic and Pacific Arctic and sub-Arctic, and are managed at a regional or national level within each of the five Arctic-range countries, along with international fora used to share information and management strategies. Genetic data—primarily mtDNA control region sequences and microsatellites—have played an important role in defining appropriate management units. Here, we review the genetic studies published to date and, for the first time, present a range-wide, circumpolar analysis of levels of mtDNA diversity and differentiation in beluga stocks. Our meta analysis is based on 302 bp of overlapping mtDNA control region sequence and includes 2,933 individuals spanning all 21 recognized beluga stocks. We find that all stocks are significantly differentiated from each other, except in five cases. Belugas in the St. Lawrence Estuary are the most distinct—the stock has the lowest range-wide level of genetic diversity and, with only two haplotypes present not found elsewhere, it is also the most well differentiated. Belugas in the Barents, Kara, and Laptev Seas stock have the highest level of diversity, supporting that this geographically far-ranging stock may harbor several distinct sub-units. Our study showcases insights gained from studying species at a range-wide level, while highlighting the challenges associated with compiling and comparing data from various publications with different study designs.*

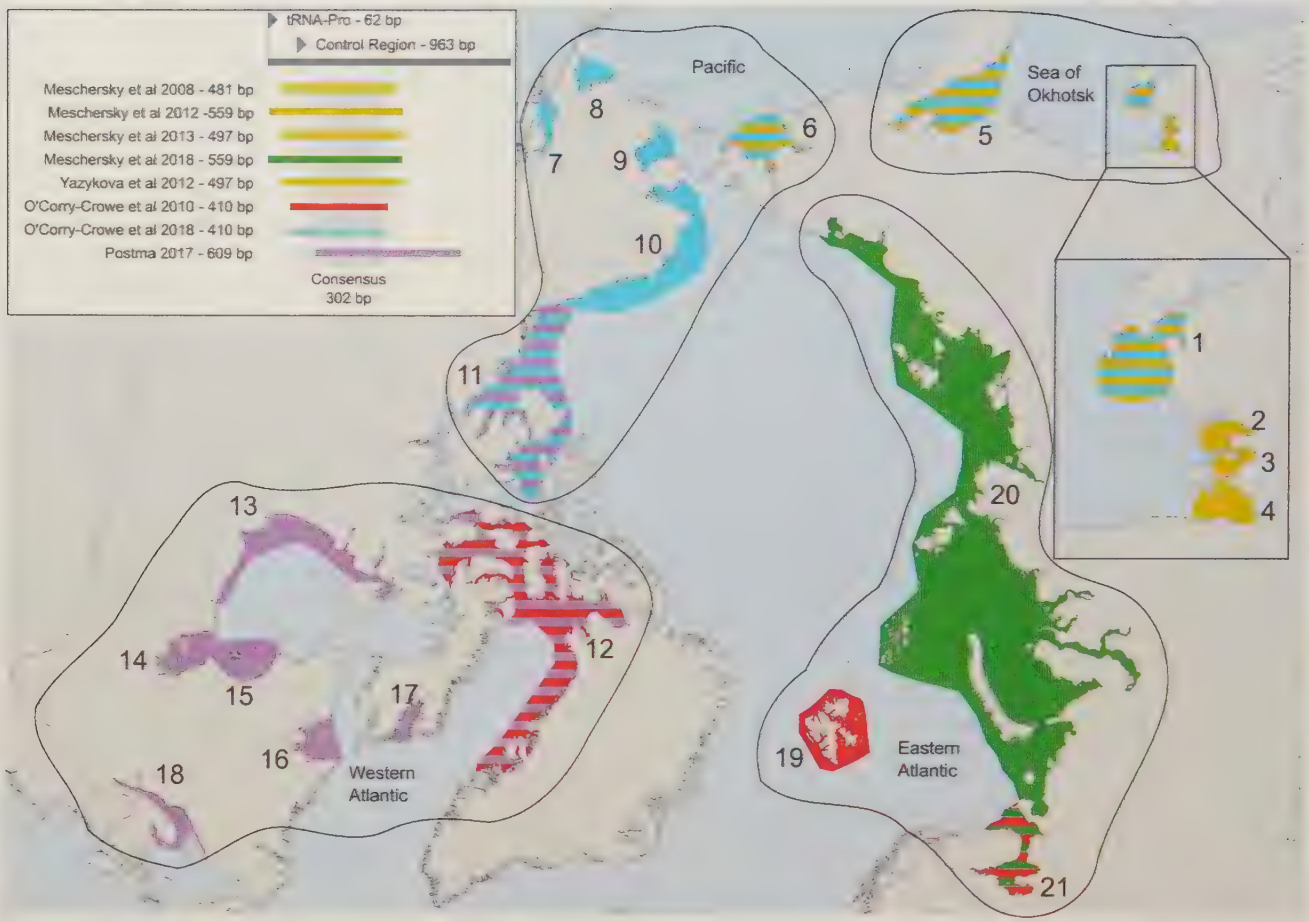


Figure 1.—Location of beluga whale stocks recognized by the Global Review of Monodontids (NAMMCO, 2018). Insert map: eastern Sea of Okhotsk. White insert (top left) shows the publications from which we retrieved mtDNA sequences for our circumpolar dataset, the mtDNA regions included in the original studies, and the position of the 302 bp overlapping sequence used in our analysis. Colors indicate the geographic range of the eight publications that contributed mtDNA squences to our study. The geographic extent of the four ad-hoc regions discussed in the main text are indicated by black lines.

Here, we review the population-level genetic data (mtDNA and microsatellites) published to date on the species. To test the genetic validity of the 21 beluga stocks presented in the GROM report (Hobbs et al., 2019), we compiled a pan-Arctic dataset of published mtDNA sequences. Because studies have not always sequenced the same region of the mitochondrial genome, we trimmed the available, aligned sequences to allow the most comprehensive dataset. Our analysis comprised 302 bp of overlapping control region sequence from 2,933 beluga individuals spanning the 21 GROM stocks. Because microsatellite data from different studies cannot be combined or compared when no standard reference sample has been included, we were unable to carry out a similar range-wide analysis of available microsatellite data and instead present an overview of the studies published.

Methods

Literature Review

We compiled the published population genetic literature on belugas based on mtDNA and microsatellites. We searched Google Scholar using the search terms: "Beluga whale," "*Delphinapterus leucas*," "population genetics," "population structure," "mtDNA," and "microsatellites". Furthermore, we looked through the refer-

Table 1.—Publications with population-level genetic data from belugas, including numbers of individuals analyzed and type of genetic marker used.

Publication	Genetic marker (n)	Stock in present study
Patenaude et al., 1994	DNA fingerprints	
Murray et al., 1995	Major Histocompatibility Complex (233)	
Buchanan et al., 1996	Microsatellites (100)	
O'Corry-Crowe et al., 1997	mtDNA (324)	
Brennin et al., 1997	RFLP (95)	
Brown Gladden et al., 1997	mtDNA (628)	
Brown Gladden et al., 1999	Microsatellites (640)	
O'Corry-Crowe et al., 2002	mtDNA (427)	
Palsböll et al., 2002	mtDNA (195)	
de March et al., 2002	mtDNA (481)	
	Microsatellites (458)	
de March et al., 2003	mtDNA (714)	
	Microsatellites (555)	
Meschersky et al., 2008	mtDNA (28)	
O'Corry-Crowe et al., 2010	mtDNA (122)	White Sea
	Microsatellites (83)	
Borisova et al., 2012	Microsatellites (161)	
Yazykova et al., 2012	mtDNA (256)	
	Microsatellites (209)	
Turgeon et al., 2012	mtDNA (1605)	
	Microsatellites (1605)	
Colbeck et al., 2012	Microsatellites (1524)	
Meschersky et al., 2013	mtDNA (211)	Anadyr and Shelikhov
	Microsatellites (175)	
O'Corry-Crowe et al., 2015	mtDNA (10)	
	Microsatellites (10)	
O'Corry-Crowe et al., 2016	mtDNA (978)	
	Microsatellites (816)	
Postma, 2017	mtDNA (2501)	Eastern Beaufort Sea, eastern Hudson Bay, western Hudson Bay, James Bay, Ungava Bay, Cumberland Sound, and St. Lawrence Estuary
	Microsatellites	
Skovrind et al., 2017	mtDNA (2)	
Glazov et al.[1]	mtDNA	Barents, Kara, and Laptev Seas
Meschersky et al., 2018	mtDNA (58)	White Sea
Citta et al., 2018	Microsatellites (516)	
O'Corry-Crowe et al., 2018	mtDNA (1444)	Cook Inlet, Bristol Bay, eastern Chukchi Sea, eastern Bering Sea, eastern Beaufort Sea, Anadyr, Shelikhov, Sakhalin-Amur
	Microsatellites (1116)	
Shpak et al., 2019	mtDNA (484)	Sakhalin-Amur, Ulbansky Bay, Tugursky Bay and Udskaya Bay

[1]Glazov, D. M., I. G. Meschersky, D. M. Kuznetsova, V. V. Krasnova, M. V. Gavrilo, D. A. Udovik, and O. V. Shpak. Review of current knowledge on beluga whale of the Russian northern seas. Unpubl. ms.

ence lists of the publications retrieved via Google Scholar for any publications that had not been retrieved in our original search. We also went through the recent GROM status review to ensure that we included all relevant papers used to define the 21 beluga stocks (Hobbs, et al., 2019). For each publication, we compiled information on genetic markers used, sample sites, and any sample overlap among studies.

Our Use of the Term "Stock"

Several terms have been used in the literature to delimit distinct beluga units, including "population," "subpopulation," "management unit," and "stock". Although they have at times been used interchangeably, their meanings differ. "Population" and "subpopulation" indicate different levels of reproductively isolated groups. "Management unit" indicates that each unit is being managed separately, and "stock" is a term implying that a natural resource is harvested as a single unit. None of these accurately describe distinct beluga units. We adopt the use of "stocks" as it is defined in the GROM report, which is to identify distinct beluga summering grounds (NAMMCO, 2018).

mtDNA Data Compilation

The main objectives of this study were to compile a range-wide dataset of beluga mtDNA sequences, to test the genetic validity of the GROM stocks, and to further our understanding of pan-Arctic patterns of structuring and variation in the species. When generating our dataset, we wanted to 1) maximize the length of overlapping mtDNA sequence, while also maximizing the number of individuals analyzed, 2) ensure our dataset included individuals from all 21 stocks, and 3) avoid duplicate sequences from individuals sequenced in multiple studies. This was achieved using data from eight publications (Fig. 1), including five peer-reviewed publications (Meschersky et al., 2008, 2013, 2018; O'Corry-Crowe et al., 2010, 2018), two conference papers (Meschersky et al., 2012; Yazykova et al., 2012) and a Ph.D. thesis (Postma, 2017). Information on haplotype frequencies within stocks and DNA sequence accession numbers from Meschersky et al. (2008, 2012, 2013, 2018) and Yazykova et al. (2012) were kindly provided by the authors. Two publications (O'Corry-Crowe et al., 2010, 2018) presented tables of haplotype frequencies and haplotype GenBank accession numbers, from which we reconstructed the original datasets. Haplotype frequencies from Postma (2017) were presented in the thesis, and the corresponding sequences were provided by the author. Sequences were assigned to the 21 GROM stocks using sample site information from the original publications. In cases where the same individuals were analyzed in multiple studies, only the sequence from the most recent publication was used. Sequences collected outside recognized GROM stocks, e.g., from migrating individuals or individuals with insufficient information, were omitted from further analysis.

mtDNA Data Analysis

The mtDNA sequences were aligned using ClustalW (Larking et al., 2007) with default settings and trimmed in the 5' and 3' end to only include genetic regions covered by all individuals. This resulted in a final dataset of 2,933 individuals with 302 bp of overlapping control region sequence. Haplotypes were named GROM_XX, with XX representing a two-digit sequential number starting at 01 (Supplementary Table 1)[4]. Due to the reduced sequence length, some previously unique

[4]Haplotypes found in our meta dataset and their frequencies in each of the 21 stocks recognized by GROM (NAMMCO, 2018) (provided as .xlsx file available at https://doi.org/10.7755/MFR.81.3-4.4s1).

Table 2.—Publications with population-level microsatellite data from belugas, including number of individuals and loci analyzed.

Publication	*n*	No. of loci	Markers
Buchanan et al., 1996	100	15	DlrFCB1, DlrFCB2, DlrFCB3, DlrFCB4, DlrFCB5, DlrFCB6, DlrFCB7, DlrFCB8, DlrFCB10, DlrFCB11, DlrFCB12, DlrFCB13, DlrFCB14, DlrFCB16, DlrFCB17
Brown Gladden et al., 1999	640	5	DlrFCB4b, DlrFCB5b, 464/465-1, EV37Mna, EV94Mnb
de March et al., 2002	458	15	DlrFCB1, DlrFCB2, DlrFCB3, DlrFCB4, DlrFCB5, DlrFCB8, DlrFCB10, DlrFCB11 DlrFCB13, DlrFCB14, DlrFCB16, DlrFCB17, Gme464/465, MnoEV37Mn, MnoEV94Mn
de March et al., 2003	555	15	DlrFCB1, DlrFCB2, DlrFCB3, DlrFCB4, DlrFCB5, DlrFCB8, DlrFCB10, DlrFCB11, DlrFCB13, DlrFCB14, DlrFCB16, DlrFCB17, Gme464/465, MnoEV37Mn, MnoEV94Mn
O'Corry-Crowe et al., 2010	83	8	CS415,CS417, CS468, EV37, EV94, DlrFCB3, DlrFCB5, DlrFCB17
Turgeon et al., 2012	1,605	13	EV37, EV94, FCB1, FCB2, FCB3, FCB4, FCB5, FCB8, FCB10, FCB11, FCB13, FCB14, FCB17
Yazykova et al., 2012	209	19	DlrFCB1, DlrFCB2, DlrFCB3, DlrFCB4, DlrFCB5, DlrFCB6, DlrFCB8, DlrFCB10, DlrFCB11, DlrFCB13, DlrFCB14, DlrFCB16 DlrFCB17, EV37Mn, EV94Mn, 415/416, 417/418, 464/465, 468/469
Colbeck et al., 2012	1,524	13	EV37, EV94, FCB1, FCB2, FCB3, FCB4, FCB5, FCB8, FCB10, FCB11, FCB13, FCB14, FCB17
Borisova et al., 2012	161	8	DlrFCB4, DlrFCB5, DlrFCB17, EV94Mn, 415/416, 417/418, 464/465, 468/469
Meschersky et al., 2013	175	9	DlrFCB4, DlrFCB5, DirFCB17, EV37Mn, EV94Mn, 415/416, 417/418, 464/465, 468/469
O'Corry-Crowe et al., 2015	10	8	CS415, CS417, CS468, EV37, EV94, DlrFCB3, DlrFCB5, DlrFCB17
O'Corry-Crowe et al., 2016	816	8	CS415, CS417, CS468, EV37, EV94, DlrFCB3, DlrFCB5, DlrFCB17
O'Corry-Crowe et al., 2018	1,116	8	CS415, CS417, CS468, EV37, EV94, DlrFCB3, DlrFCB5, DlrFCB17
Citta et al., 2018	516	7	CS415, CS417, EV37, EV94, DlrFCB3, DlrFCB5, DlrFCB17

haplotypes collapsed into the same GROM_XX haplotype (Supplementary Table 2)[5]. To visualize the relationships among mtDNA haplotypes, we used the sequence alignment to construct a median spanning haplotype network (Bandelt et al., 1999) using Popart 1.7[6].

We used two parameters to estimate levels of diversity within stocks (H and π), both calculated using Arlequin (Excoffier and Lischer, 2010). These estimators have been widely used in beluga genetics, and report levels of diversity in different ways. Haplotype diversity (H) delimits the proportion of unique haplotypes within each stock, whereas nucleotide diversity (π) uses the average number of nucleotide differences between all possible pairs of sequences within each stock. Thus, stocks with a high proportion of unique haplotypes will have a high level of H, without consideration of how different the haplotypes are, while stocks with many variable sites will have a high level of π, ignoring the number of unique haplotypes. Levels of differentiation among all stock pairs was estimated by the fixation index F_{ST} using Arlequin 3.5 (Excoffier and Lischer, 2010). Levels of significance were corrected for multiple testing by dividing 0.05 by the number of tests (210), yielding a corrected p value of 0.00024.

To assess the broad-scale, macrogeographic patterns of mtDNA diversity across the species range, and to assist readers less familiar with Arctic geography, we divided the 21 stocks into four geographic regions ad hoc (Fig. 1):

1. Sea of Okhotsk, including Sakhalin-Amur, Ulbansky Bay, Tugursky Bay, Udskaya Bay, and Shelikov Bay stocks; these stocks all exclusively inhabit the Sea of Okhotsk during winter.
2. Pacific, including Anadyr Estuary, Cook Inlet, Bristol Bay, eastern Bering Sea, eastern Chukchi Sea, and eastern Beaufort Sea stocks, which all inhabit the Bering Sea and adjacent waters during winter.
3. Western Atlantic, including eastern High Arctic, western Hudson Bay, James Bay, eastern Hudson Bay, Ungava Bay, Cumberland Sound, and St. Lawrence Estuary stocks, which spend winters in Baffin Bay, Labrador Sea, and Hudson Strait, or remain resident in adjacent bays.
4. Eastern Atlantic, including Svalbard, Barents, Kara, and Laptev Seas, and White Sea stocks. These three stocks are assumed to inhabit separate geographic regions during winter but are all located in waters connected to the north-eastern Atlantic Ocean.

Results

Literature Review

We retrieved 27 beluga publications with population-level genetic data (Table 1). In total, >4,500 beluga individuals have been sequenced for part of their mitochondrial genome. Twenty-one publications are based on the analysis of mtDNA sequences, while 13 of the 27 publications include microsatellite data. Ten publications analyze both mtDNA sequences and microsatellite data (Table 1).

Our literature review revealed a regional publication bias, with some geographic regions more intensely studied than others. Only three of the 27 publications identified in this review include samples from the eastern Atlantic region (Fig. 1), by far the least-studied region. The Sea of Okhotsk is included in seven publications. The Pacific and western Atlantic regions are the most studied regions, and have been included in 16 and 14 publications, respectively. The eastern Atlantic region is covered by fewer genetic studies, although the Svalbard and White Sea stocks have been inves-

[5]GROM_XX haplotype numbers and the corresponding NCBI accession numbers of sequences included in our 302 bp dataset (provided as .xlsx file available at https://doi.org/10.7755/MFR.81.3-4.4s2).

[6]Available from http://popart.otago.ac.nz.

tigated using other non-genetic methodologies including telemetry and aerial surveys (Lydersen et al., 2001; Glazov et al., 2010). The Barents, Kara, and Laptev Seas stock has only been analyzed genetically in Meschersky et al. (2018).

Microsatellites

Microsatellites have played an important role in providing valuable information regarding the subdivision of beluga stocks (Brown Gladden et al., 1999; de March and Postma, 2003; O'Corry-Crowe et al., 2010, 2015; Turgeon et al., 2012; Meschersky et al., 2013). Microsatellites are long repeats of short motifs (<10 bp sequences) that can be found throughout the nuclear genome. The variation in microsatellites is captured by the length of the repetitive sequences (allele size), reflecting the varying number of times the short motifs are repeated (Vieira et al., 2016).

Microsatellites evolve at an elevated rate compared to other nuclear markers making them suitable for investigations of recent evolutionary changes (Ellegren, 2004). They have been used in local and regional studies to investigate kinship in pods (Colbeck et al., 2013), genetic mark-recapture (Citta et al., 2018), stock assignment (O'Corry-Crowe et al., 2018), and impacts of changing sea ice conditions (O'Corry-Crowe et al., 2016).

However, in a pan-Arctic context, the methodology is limited by the fact that allele sizes are influenced by lab-specific practices, and the data generated by different labs are therefore not directly comparable, unless they are calibrated by one or more reference samples. These difficulties have been overcome in work on other species by the inclusion of reference samples by all labs that contribute to the compiled data (Ellis et al., 2011). However, this requires coordinated efforts among research groups prior to the onset of the work, and is perhaps a more realistic approach for the investigation of commercially important species. Nevertheless, to provide an overview of the microsatellite literature, we compiled an exhaustive list of the studies published to date and present details of the specific microsatellite markers used in each study in Table 2.

mtDNA Data Analysis

Aligning and trimming of mtDNA sequences resulted in 302 bp overlapping sequence of the control region (Fig. 1), representing 2,933 individuals and all 21 GROM stocks (Supplementary Table 1). Sample sizes of individual stocks ranged from 22 (Barents, Kara, and Laptev Seas) to 579 (eastern Chukchi Sea). Our dataset included 71 haplotypes defined by 16 variable sites. The median-spanning network revealed two major haplogroups differentiated by four variable sites (Fig. 2). Haplogroup A harbors samples from all four geographic regions, while Haplogroup B only includes samples from the western Atlantic region. Within Haplogroup A, all haplotypes are differentiated from neighboring haplotypes by only one variable site. This is also the case for all haplotypes within haplogroup B, except for haplotypes found in the St. Lawrence Estuary, which are separated from other haplogroup B haplotypes by two variable sites (Fig. 2).

Haplotypes GROM_01, GROM_02, and GROM_23 are found at the highest frequencies in our trimmed dataset and result from the collapse of 43, 11, and 7 haplotypes, respectively, from the published, longer sequences that were trimmed in our analysis (Supplementary Table 1). GROM_01 is found in 809 individuals from 19 stocks, GROM_02 is found in 365 individuals from 10 stocks, and GROM_23 is found in 461 individuals from 11 stocks. Twenty-four haplotypes are found in less than five individuals.

Levels of haplotype diversity (H) across the 21 beluga stocks range from 0.19 in St. Lawrence Estuary and Bristol Bay, to 0.87 in Barents, Kara, and Laptev Seas (Fig. 3a). Nucleotide diversity (π) ranges from 0.001 in Ulbansky Bay to 0.014 in eastern Hudson Bay (Fig. 3b). Five stocks have $\pi < 0.002$ (White Sea, Bristol Bay, Ulbansky Bay, Shelikov Bay, and Anadyr Estuary), and two stocks have $\pi > 0.01$ (James Bay and eastern Hudson Bay). The remaining 15 stocks have π between 0.002 and 0.007.

The fixation index F_{ST} shows large variation and ranges from 0.00 to 0.93 (Table 3). All but five F_{ST} values are significant. Pairwise comparisons between (Tugursky Bay/Udskaya Bay), (Ulbansky Bay/Bristol Bay), (Ungava Bay/western Hudson Bay), (Ulbansky Bay/western Hudson Bay), and (Svalbard/Anadyr) are not significant after Bonferroni correction for multiple testing ($\alpha = 0.00024$).

Discussion

The mitochondrial genome is a non-recombining, independently evolving genome, which is passed on from mother to offspring (Hutchison et al., 1974). The development of easy-to-use, highly conserved primers that amplify targeted mtDNA fragments, coupled with high levels of intraspecific diversity, has made the control region the marker of choice in population genetics and phylogeography (Kocher et al., 1989; Ballard and Whitlock, 2004). Mitochondrial DNA analysis has been applied frequently in beluga research and has revealed high levels of diversity and differentiation across the belugas' range, establishing it as a valuable tool in beluga conservation and management (Brown Gladden et al., 1997; O'Corry-Crowe et al., 1997, 2002; Palsbøll et al., 2002; Meschersky et al., 2008, 2013, 2018).

However, mtDNA has inherent limitations (Balloux, 2010). The lack of recombination and the small size of the mitochondrial genome (16,386 bp (Kim et al., 2017)) makes it susceptible to stochastic events, and intraspecific patterns of mtDNA variability may not accurately reflect the evolutionary history of a population (Toews and Brelsford, 2012). Further, the maternal inheritance means that only the female lineage is reflected in mtDNA. Nevertheless, as long as these limitations are recognized, mtDNA remains a valuable resource for investigating phylogeographic patterns across a species range.

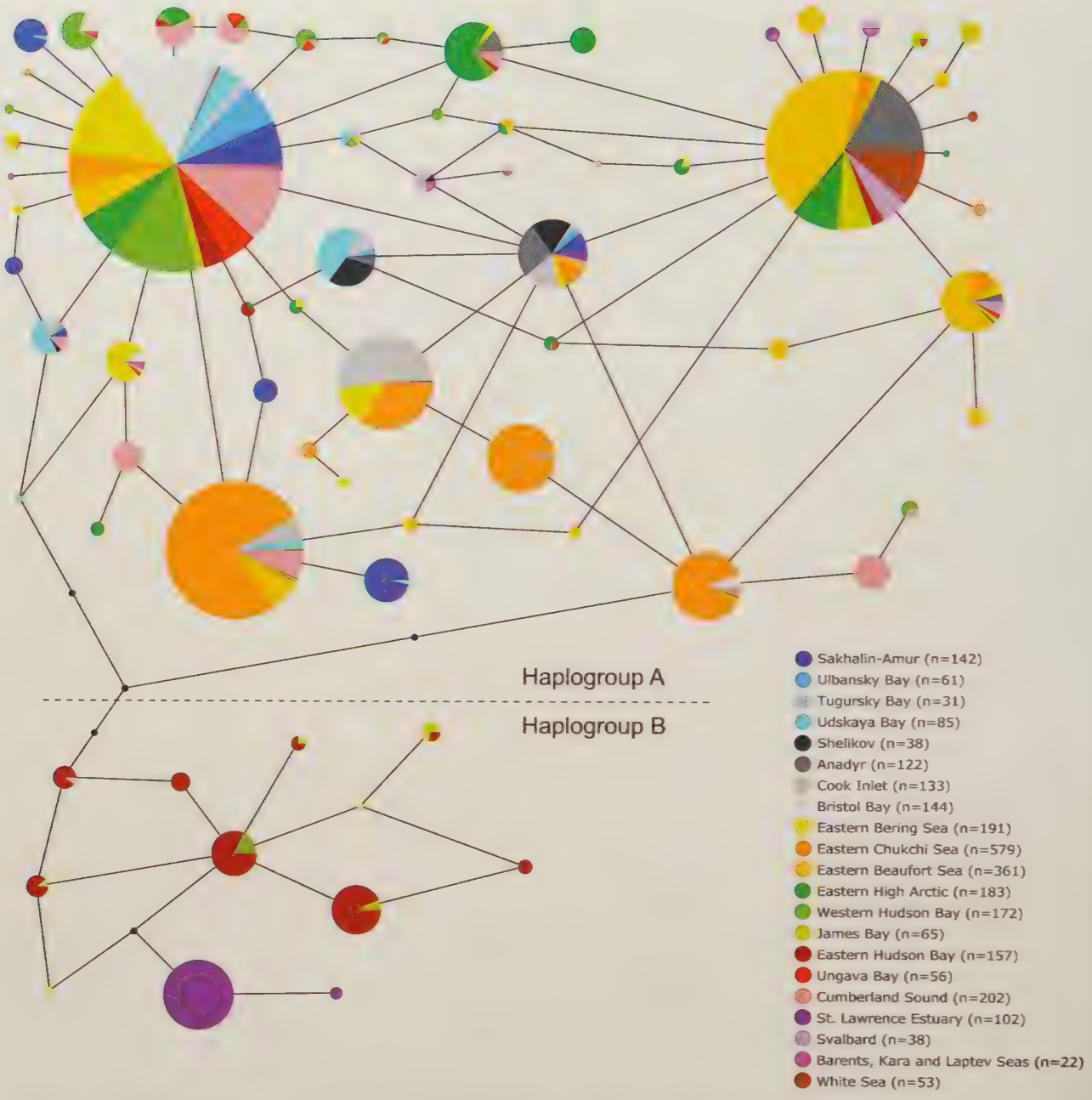


Figure 2.—Median-spanning network of 71 haplotypes across 2,933 mtDNA sequences from 21 beluga stocks. Each haplotype is represented by a circle colored according to the stocks where the specific haplotype was found. Black dots indicate haplotypes not sampled in the data. Circle size indicates relative haplotype frequency.

Circumpolar Insights

To carry out a pan-Arctic meta analysis that allowed the direct comparison of stock diversity and differentiation across the beluga range, the complexity of the original data was necessarily reduced, as our analysis included 302 bp of overlapping sequences from 2,933 individuals and all 21 GROM stocks.

We found 71 haplotypes defined by 16 variable sites. Our haplotype network revealed two major haplogroups, A and B (Fig. 2). Haplogroup A included individuals from 20 of the 21 GROM stocks, excluding St. Lawrence Estuary, individuals from which were exclusively found in Haplogroup B. Our results lack the genetic structure reported in a previous analyses of 609 bp sequences (n=2,501) and complete mitochondrial genomes (n=106) from Canadian belugas (Postma,

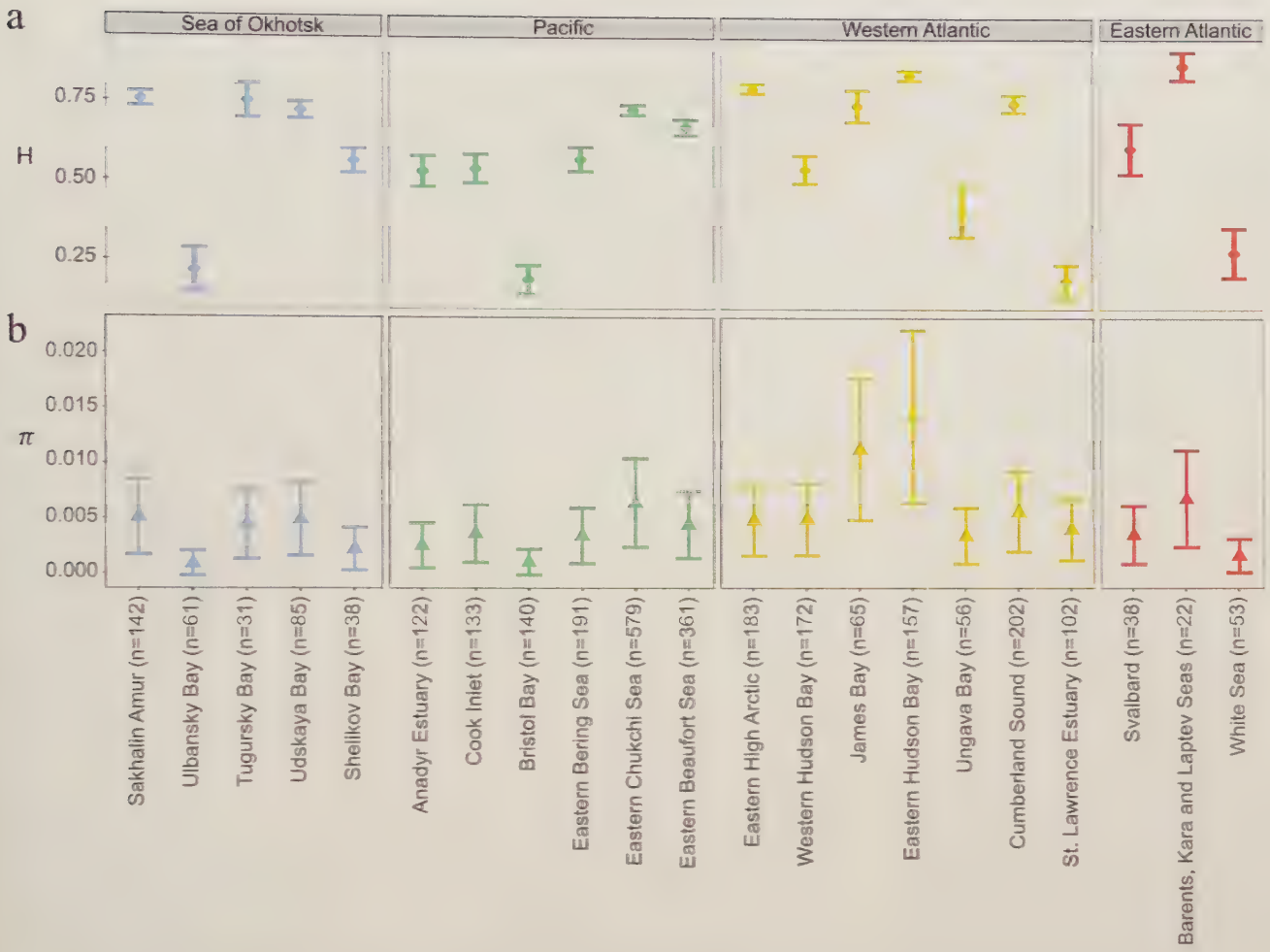


Figure 3.—Levels of genetic diversity in the 21 beluga stocks. a) Haplotype diversity (H) and, (b) Nucleotide diversity (π).

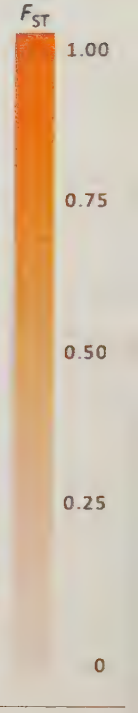
2017), which in our analysis cluster together with no apparent structuring in Haplogroup A. The analysis of the longer sequences revealed two well-differentiated haplogroups, highlighting the limited resolution of our 302 bp mtDNA dataset, and hence caution should be exercised when interpreting results.

Our diversity estimates show large variation among beluga stocks both in haplotype diversity (H), which counts the proportion of unique haplotypes in each stock, and nucleotide diversity (π), which describes how different the sequences are. The lowest H was found in Bristol Bay (0.19), St. Lawrence Estuary (0.19), Ulbansky Bay (0.22), and White Sea (0.28) (Fig. 3a). This is supported by corresponding low levels of π in these stocks (Bristol Bay and Ulbansky Bay (0.001), White Sea (0.002) (Fig. 3b)). However, we find relatively high π in St. Lawrence Estuary (0.004), which reflects that this stock has only two unique, but more diverse haplotypes (Fig. 2). The low levels of mtDNA diversity in the former beluga stocks could have arisen from several evolutionary processes, including 1) low levels of diversity in the founding individuals, 2) insufficient time since establishment of the stock to accumulate new mutations, 3) low levels of females migrating into the stock, and 4) genetic drift—a stochastic mechanism removing rare haplotypes—which affects small populations to a higher degree than larger populations. The St. Lawrence Estuary stock is less than half the size of the three other low-diversity stocks, which suggests that it is shaped by genetic drift to a larger degree (Hobbs, et al., 2019).

The Barents, Kara, and Laptev Seas stock has the highest level of H (0.87) and π (0.14) (Fig. 3). This could reflect the stock harboring multiple distinct, but as-yet undefined stocks, as has been suggested (Hobbs, et al., 2019). Substructuring within the stock would result in inflated diversity estimates. This is likely, as the Barents, Kara, and Laptev Seas stock has an extensive geographic range (Fig. 1) yet has only been included in one genetic study (Meschersky et al., 2018).

Table 3.—Levels of differentiation F_{ST} between the 21 beluga stocks recognized by GROM (NAMMCO, 2018). Values in bold are insignificant with p > 0.00024.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Sea of Okhotsk	1 Sakhalin-Amur		0.14	0.15	0.16	0.46	0.55	0.45	0.18	0.17	0.18	0.48	0.29	**0.14**	0.41	0.55	0.13	0.10	0.86	0.54	0.27	0.61
	2 Ulbanskiy Bay			0.16	0.17	0.70	0.68	0.53	**0.01**	0.05	0.22	0.49	0.26	0.03	0.41	0.52	0.03	0.07	0.91	0.72	0.36	0.83
	3 Tugurskiy Bay				**0.00**	0.33	0.53	0.39	0.25	0.11	0.18	0.40	0.23	0.10	0.27	0.45	0.13	0.10	0.86	0.49	0.13	0.65
	4 Udskaya Bay					0.25	0.49	0.38	0.25	0.15	0.19	0.41	0.26	0.14	0.31	0.48	0.16	0.13	0.85	0.47	0.17	0.58
	5 Shelikov Bay						0.52	0.43	0.74	0.47	0.32	0.41	0.44	0.44	0.28	0.47	0.56	0.39	0.87	0.52	0.34	0.68
	6 Anadyr Estuary							0.53	0.72	0.52	0.38	0.03	0.25	0.50	0.11	0.56	0.60	0.47	0.88	**0.04**	0.23	0.09
Pacific	7 Cook Inlet								0.59	0.38	0.20	0.46	0.44	0.43	0.39	0.55	0.48	0.38	0.88	0.53	0.37	0.62
	8 Bristol Bay									0.07	0.24	0.53	0.31	0.03	0.51	0.59	0.03	0.08	0.93	0.77	0.46	0.84
	9 Eastern Bering Sea										0.18	0.42	0.20	0.06	0.39	0.56	0.06	0.07	0.88	0.54	0.19	0.61
	10 Eastern Chukchi Sea											0.33	0.27	0.21	0.34	0.56	0.21	0.13	0.81	0.38	0.21	0.45
	11 Eastern Beaufort Sea												0.18	0.43	0.10	0.59	0.46	0.40	0.83	0.04	0.16	0.09
Western Atlantic	12 Eastern High Arctic													0.21	0.21	0.56	0.22	0.21	0.85	0.28	0.07	0.33
	13 Western Hudson Bay														0.36	0.51	**0.01**	0.05	0.85	0.50	0.18	0.58
	14 James Bay															0.35	0.34	0.35	0.71	0.06	0.08	0.12
	15 Eastern Hudson Bay																0.49	0.53	0.43	0.47	0.41	0.53
	16 Ungava Bay																	0.04	0.88	0.58	0.23	0.70
	17 Cumberland Sound																		0.84	0.46	0 18	0.53
	18 St. Lawrence Estuary																			0.85	0.84	0.88
Eastern Atlantic	19 Svalbard																				0.19	0.09
	20 Barents, Kara and Laptev Seas																					0.37
	21 White Sea																					



All but five pairs of beluga stocks are significantly differentiated ($p < 0.00024$) indicating that this dataset of only 302 bp in most cases supports the 21 stocks recognized by GROM (Table 3). The lack of significant differentiation between western Hudson Bay and Ungava Bay is a result of shared haplotypes (Fig. 2). Although western Hudson Bay has 15 haplotypes and Ungava Bay has 10 haplotypes, 201 out of 228 individuals (88%) found in the two stocks belong to seven shared haplotypes (Supplementary Table 1). Haplotype sharing may be explained by their close geographic proximity (Fig. 1), or reflect that individuals from western Hudson Bay were sampled as they migrate through the Hudson Strait just outside Ungava Bay (Lewis et al., 2009; Hobbs, et al., 2019).

Tugursky Bay and Udskaya Bay, which are adjacent stocks in the Sea of Okhotsk, are not differentiated in our F_{ST} analysis; 95% of individuals from the two stocks belong to one of four shared haplotypes (Fig. 2, Supplementary Table 1). This could reflect that a single genetic unit is distributed across the two bays, which is further supported by similar H and π levels (Fig. 3). A previous study using longer mtDNA fragments and 19 microsatellite loci was also unable to differentiate between them (Yazykova et al., 2012). However, GROM evaluations are based on a composite of data, and Tugursky Bay and Udskaya Bay belugas use separate summering grounds and show behavioral differences towards motorized boats (Hobbs, et al., 2019).

Our analysis was unable to differentiate between several stocks that are otherwise separated by large geographic distances, in large part reflecting the low resolution in our data. The pattern could also be explained by shared recent demographic histories, or the colonization of one area from the other, but we consider this less likely. For example, Ulbansky Bay and Bristol Bay are separated by more than 3,000 km (Fig. 1). Both stocks harbor haplotype GROM_01 at ~90% frequency (Supplementary Table 1), and additional haplotypes are closely related to GROM_01, resulting in low levels of both H and π (Fig. 3). During the trimming of the sequence alignment to 302 bp, a number of informative sites were lost; GROM_01 includes 43 collapsed haplotypes from the original studies (Supplementary Table 2). This could indicate that longer sequences might enable us to distinguish Ulbansky Bay and Bristol Bay, although when we analyzed the available 410 bp mtDNA sequence shared by the two stocks, they remain indistinguishable.

Our F_{ST} analysis supports that St. Lawrence Estuary is the most divergent, underscoring the uniqueness of this stock (Gladden et al., 1999; de March and Postma, 2003; Postma, 2017). This is in agreement with the haplotype network in which the two St. Lawrence haplotypes are not shared with any other stock and are differentiated from their nearest neighbor by two variable sites (Fig. 2).

Limitations of mtDNA

Our meta analysis of 302 bp pan-Arctic sequences from 2,933 indi-

viduals highlights that, even with large sample sizes and range-wide sampling, inferences based on short control region mtDNA fragments are limited. In the light of this, short mtDNA markers may still have a role to play in future genetic work in belugas, providing an accessible initial exploratory tool to help form hypotheses for further testing. Full mitochondrial genomes offer more information and higher resolution (Postma, 2017; Skovrind et al., 2017). Mitochondrial genome analyses have been used in a number of other whale species to make a wide variety of inferences, including historic female population size, detailed phylogeographic structuring, and the existence of subspecies (Morin et al., 2010, 2018; Van Cise et al., 2019), illustrating the potential of mitogenomes in beluga research in providing a clearer picture of the history and structuring of maternal lineages. However, mitochondrial data is not able to elucidate the demography and history of both sexes, including levels of male migration and patterns of gene flow among stocks, which require insights from the nuclear genome. Hence, mtDNA should not be used as a stand-alone tool with which to differentiate stocks, but should be used, with caution, as a component in a multidisciplinary effort including other methodologies, e.g. telemetrics, aerial surveys, and behavioral studies, where available, as has been applied in the GROM stock evaluation (Hobbs, et al., 2019). For example, behavior, social bonds, migration routes, site fidelity, and possibly other traits might delineate stocks, even in the absence of genetic differentiation, as is the case for Tugursky Bay and Udskaya Bay in the Sea of Okhotsk.

Perspectives

The redistribution of belugas in the face of Arctic climate change is of high conservation concern and will require cooperation and coordination across the circumpolar range of the species (Laidre et al., 2015). Our review highlights that obtaining genetic insights across the species range is a challenge with the available data. This severely limits range-wide inferences, which is vital for understanding widely distributed species, such as belugas. Facing this challenge, a natural next step in informing the management and conservation of belugas with genetics is the transition to genome-wide sequencing methodologies, which analyze tens of thousands to millions of genetic markers across the nuclear genome. This will enable high-resolution insights into levels of differentiation and diversity, which will aid our understanding of current demographic processes in species.

Future range-wide genetic beluga studies could 1) identify evolutionary lineages and their divergence times to better understand the demographic history of the species, 2) estimate gene flow between populations to determine their current connectivity and enable tracking of future changes in gene flow patterns, and 3) identify genes under selection to inform managers of local populations with unique adaptations to their specific habitats. Such work will benefit from the recent release of a high-quality beluga reference nuclear genome (Jones et al., 2017), which offers a valuable resource for future genomic studies of the species (Allendorf, 2017). However, with new methods come new challenges. The transition from mtDNA and microsatellites to genome-wide sequencing requires appropriate lab and computational facilities and can be, despite ever-declining sequencing costs, prohibitively expensive to implement compared with methodologies that are already in wide use in beluga genetic research.

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Aerial Surveys of Bristol Bay Beluga Whales, *Delphinapterus leucas*, in 2016

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ABSTRACT—Beluga whales, (Delphinapterus leucas), *of the Bristol Bay stock were counted from 7 to 11 July 2016, during aerial surveys in Bristol Bay, Alaska. These surveys were a follow-up of surveys flown in Bristol Bay in 1993, 1994, 1999, 2000, 2004, and 2005, and used the same methods. Nine surveys were flown during 7–11 July. The total count of belugas per survey ranged from 484 to 1,024 (= 660; CV = 0.26). Correcting the average count for the number of belugas that are diving and not available to be sampled (2.62) and the proportion of calves (1.18) that cannot be seen from the aircraft suggests there are ~2,040 belugas (660 × 2.62 × 1.18) in Bristol Bay. The mean and range of counts made in 2016 is similar to those in 2004 and 2005 suggesting that the population growth observed during 1993–2005 has slowed or ceased. The greatest challenge with how belugas are surveyed within Bristol Bay is the difficulty in counting large groups. Separate counts of large groups had high variance and we suggest future surveys consider photo-documenting groups to determine if groups of belugas can be counted more consistently or using video to adjust for beluga behavior in real-time.*

Introduction and Methods

Beluga whales, *Delphinapterus leucas*, are small cetaceans (≤5.5 m), that live in seasonally ice-covered waters in Arctic and subarctic regions. The Bristol Bay stock of beluga whales is one of five known stocks that frequent Alaska waters, the other stocks being the Cook Inlet, eastern Bering Sea, eastern Chukchi Sea, and Beaufort Sea stocks (Frost and Lowry, 1990; O'Corry-Crowe et al., 1997, 2002, 2018). The Bristol Bay stock is restricted to Bristol Bay year-round (Lowry et al., 2008; Citta et al., 2016a, b) and is genetically distinct from other stocks (O'Corry-Crowe et al., 1997, 2002, 2018).

Periodic monitoring of beluga abundance in Bristol Bay is necessary for a variety of reasons. First and foremost, the population is relatively small, numbering fewer than 3,000 belugas (Lowry et al., 2008). Second, this population is important to Alaska Natives; during 2006–2016 the annual average harvest was 23 belugas (Lowry et al., 2019). Last, Bristol Bay has a number of commercial and subsistence fisheries that pose a risk of entanglement to belugas (Frost et al.[1]), including the largest commercial sockeye salmon, *Oncorhynchus nerka*, fishery in the world (Jones et al.[2]). The last aerial survey of beluga abundance in Bristol Bay was in 2005; therefore, an updated survey was necessary to assess the status of this population.

Aerial surveys were conducted during 7–11 July 2016, to count belugas of the Bristol Bay stock in Bristol Bay, Alaska. These surveys were a follow-up of surveys flown in Bristol Bay in 1993, 1994, 1999, 2000, 2004, and 2005 (Lowry et al., 2008), and used the same methods. Aerial surveys were flown using a high-wing, twin-engine *Aero Commander*[3] with oversized bubble windows. The survey crew included a pilot, a co-pilot, two observers (one seated behind the pilot and the other behind the co-pilot on the left and right sides of the aircraft), and a data recorder seated in the rear of the aircraft. The survey was designed to cover Kvichak and Nushagak bays (Fig. 1) where essentially all reported June–July sightings of belugas have occurred (see Fig. 3 in Frost and Lowry, 1990), where belugas were sighted during previous June–July aerial surveys (Lowry et al., 2008), and where all belugas with satellite data recorders were known to range in June and July (Citta et al., 2016a).

The standard survey transect followed the entire coast of both bays 0.9 km offshore, including the lower parts of major rivers. In the wider portions of the bays, east-west transects at 1.8 km intervals were flown to cover the entire area and observers counted whales in a strip 0.9 km wide on each side of the plane. Strip widths were measured by inclinometers and angles were marked on the aircraft windows with grease pencils for reference during surveys. Survey altitude was 305 m along the coast and 150 m when surveying rivers. Airspeed was approximately 222 km/h during all surveys. All surveys were flown in early July

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[2]Jones, M., T. Sands, S. Morstad, P. Salomone, G. Buck, F. West, C. Brazil, and T. Krieg. 2013. 2012 Bristol Bay area annual management report. Alaska Dep. Fish Game, Fish. Manage. Rep. 13-20, Division of Commercial Fisheries, Anchorage, AK (avail. at www.adfg.alaska.gov/FedAidPDFs/FMR13-20.pdf).

[3]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

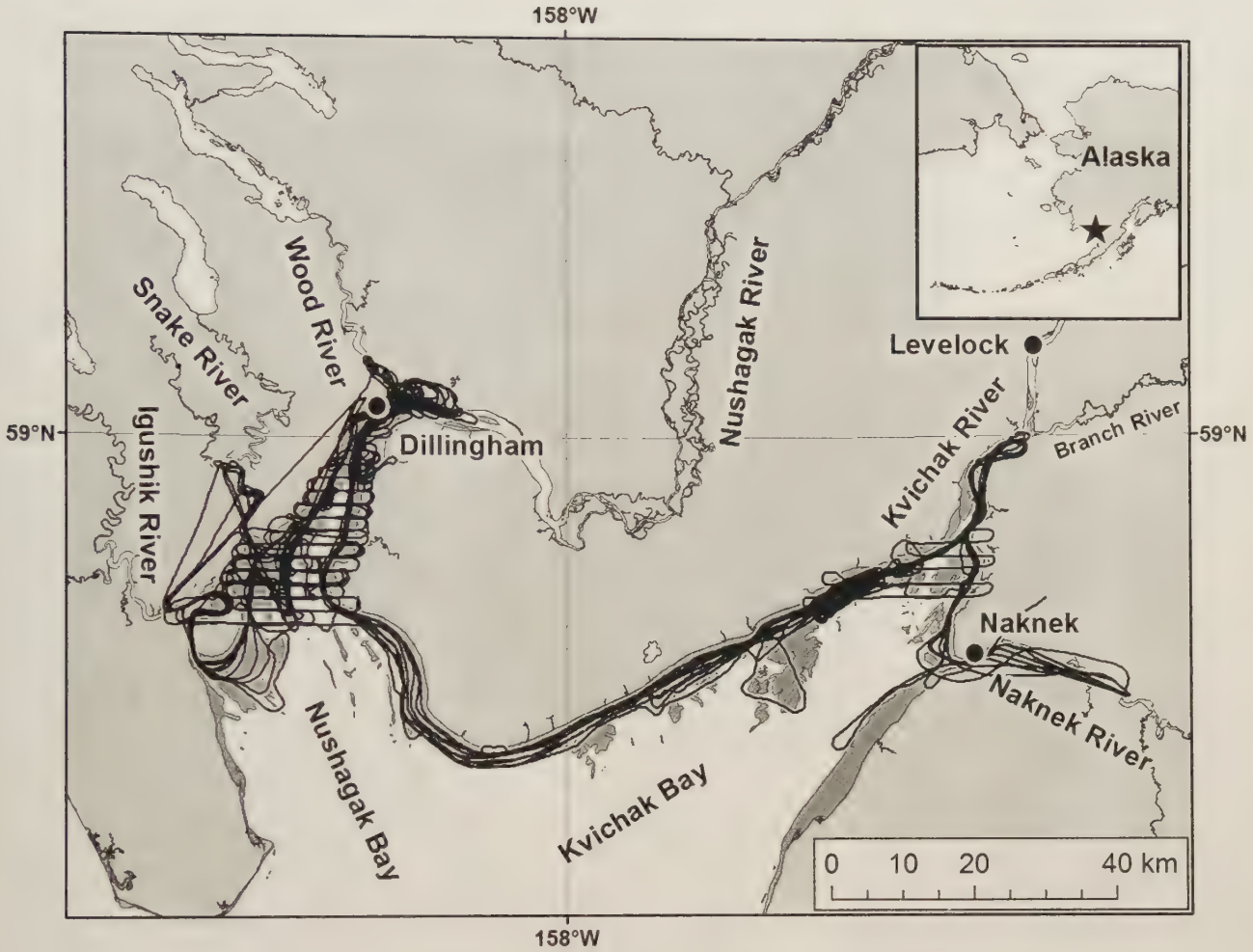

Figure 1.—Survey lines flown in Bristol Bay, Alaska, 7–11 July 2016. Dark gray areas are mudflats exposed at low tide.

when belugas aggregate near-shore and at the mouths of creeks and rivers to feed on a large sockeye salmon run.

All belugas visible at the surface along the survey track were counted. When large groups were encountered, multiple counts were made of the same group. In those situations the aircraft circled after passing by the group and flew past again on a line oriented to provide one observer the best view of the entire group. Multiple counts, usually by both observers, were recorded individually, and observers identified which counting pass was best based upon viewing conditions, such as minimum glare or position of the group relative to the aircraft (i.e., no whales in the blind spot directly under the plane). The best count for each group was used in analysis of the data. Beluga counts, weather, sea state, glare, overall sighting conditions, and other observations were entered into a computer database that also recorded the aircraft's position every 60 s. Database software was provided by the National Marine Fisheries Service (NMFS), Marine Mammal Laboratory (MML) and is also used during beluga surveys in Cook Inlet.

Results and Discussion

Nine surveys were flown during 7–11 July. The total count of belugas per survey ranged from 484 to 1,024 ($\bar{X}$ = 660; CV = 0.26) on days with good or excellent viewing conditions (eight of nine survey flights; Fig. 2; Table 1). Counts from aerial surveys are typically corrected for availability bias, defined as the bias in the count due to belugas that were diving and not available to be sampled. Frost et al. (1985) used VHF transmitters to estimate an availability correction factor of 2.75, which was later revised to 2.62 by Frost and Lowry[4]. Because beluga calves are small and gray colored and are typically not spotted in the silty (i.e., gray-colored) water, a sepa-

[4]Frost, K. J., and L. F. Lowry. 1995. Radio tag based correction factors for use in beluga whale population estimates. Working paper for Alaska Beluga Whale Comm. Sci. Workshop, Anchorage, AK, 5–7 April 1995, 12 p. Avail. from North Slope Borough, Dep. Wildlife Manage., Box 69, Barrow, AK 99723.

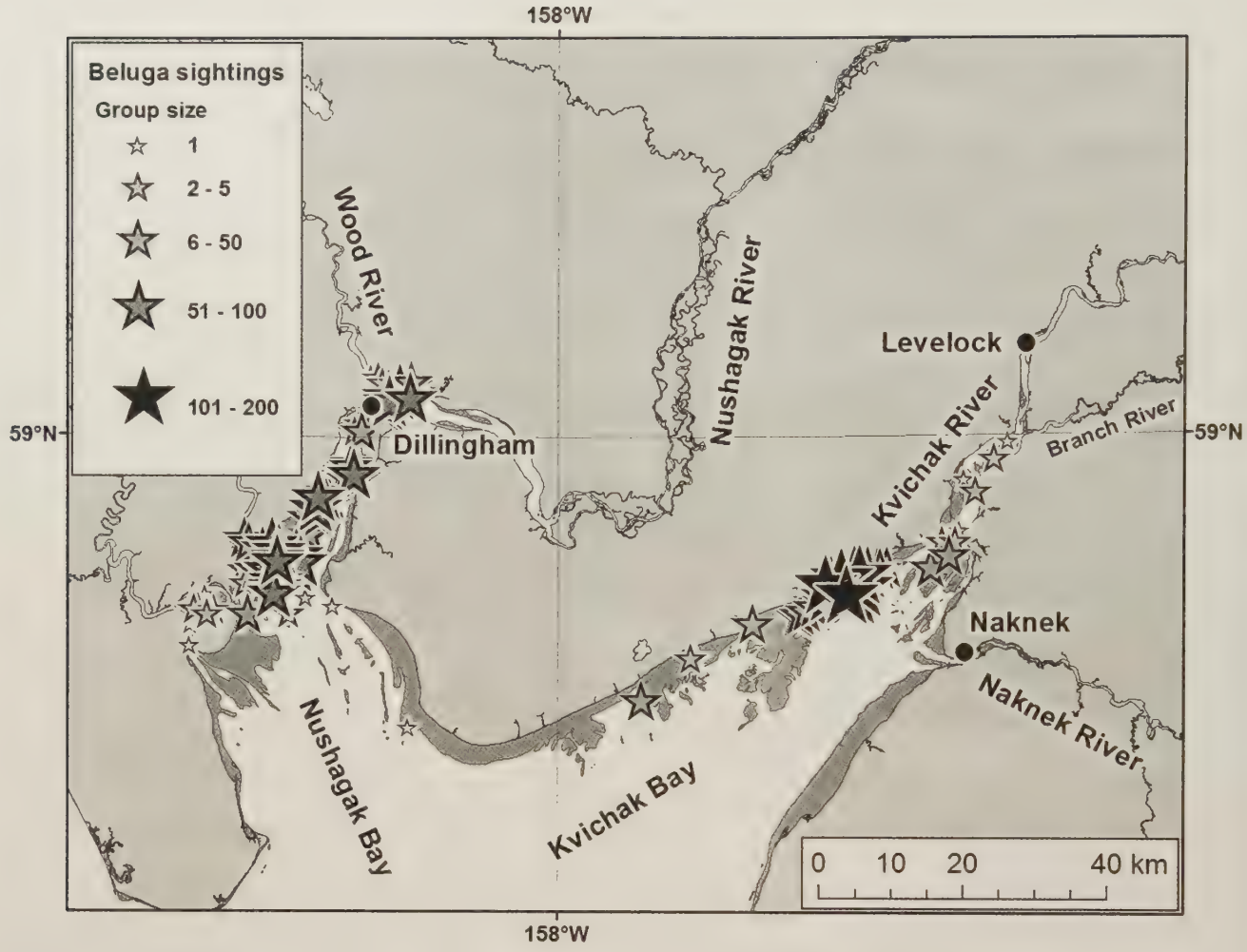

Figure 2.—Location of beluga sightings by group size in Bristol Bay, Alaska, 7–11 July 2016. Dark gray areas are mudflats exposed at low tide.

rate correction is sometimes used for calves (1.18; Brodie, 1971). Applying these corrections to the average count of belugas suggests there are 2,040 belugas (660 × 2.75 × 1.18) in Bristol Bay. Lowry et al. (2008) showed that the mean count of Bristol Bay belugas increased 4.8% per year (95% confidence interval (CI) = 2.1–7.5%) over the 12-year period, 1993–2005. After including the 2016 data in the regression analysis, increasing linear trends received the same statistical support as trends that allowed the growth in counts to lessen over time. For example, when using Akaike Information Criteria (AIC; Burnham and Anderson, 2002) to judge model support, we found that an increasing linear trend is 0.1 AIC units better than a curvilinear trend (i.e., count = year + year^2) that would allow counts to plateau or decline over time. Models within 2 AIC units of one another are considered plausible and two models within 0.1 AIC units have more-or-less equivalent support (Burnham and Anderson, 2002). Regardless, the mean and range of counts made in 2016 are similar to those in 2004 and 2005 (Fig. 3), suggesting that the population growth observed during 1993–2005 has slowed or ceased.

One goal of the survey effort in 2016 was to assess limitations of the current design and to determine if future surveys would benefit from the use of other sampling methods, such as distance sampling (e.g., Buckland et al., 1993; Thomas et al., 2010), double-observer (e.g., Buckland and Turnock, 1992; Chen, 1999), or photo/video methods (e.g., Lydersen et al., 2008; Hobbs et al., 2000a, b). We found that counts can vary considerably, even for surveys conducted on the same day and covering the same area. In 2016, the largest range of counts from replicate surveys (484 to 1,024) occurred on the same day, within a few hours of each other and with good or excellent viewing conditions (Table 1). Assuming that true population size was 2,000 belugas, then the availability correc-

Table 1.—Summary of aerial surveys for counting beluga whales in Bristol Bay, Alaska. Visibility rating scores are subjectively based upon the Beaufort wind scale and levels of glare (not shown). Because of glare, the view out one side of the aircraft is typically better than the other and large groups of belugas are typically counted from the side of the airplane that has the best visibility. Hence, when calculating proportions, we only used the better of the two visibility scores. The first survey (#1 below) was conducted as a practice run and visibility conditions were not as good as other surveys; hence, we did not use this survey when computing statistics.

Survey no.	Date	Start time	End time	Average Beaufort scale	Proportion of visibility rating scores			Count of belugas	Comments
					Excellent	Good	Fair		
1	7 July 16	15:54	18:00	2.2	0.00	0.79	0.21	200	Not used to compute statistics
2	8 July 16	10:19	13:09	1.0	0.25	0.75	0.00	484	
3	8 July 16	14:03	16:23	1.0	0.40	0.60	0.00	1,024	
4	9 July 16	10:34	13:03	1.0	0.67	0.33	0.00	756	
5	9 July 16	14:06	16:14	1.6	0.40	0.60	0.00	716	
6	10 July 16	10:31	13:35	1.8	0.29	0.71	0.00	521	
7	10 July 16	14:27	16:46	2.0	0.25	0.75	0.00	640	
8	11 July 16	10:12	13:02	1.8	0.65	0.35	0.00	595	
9	11 July 16	13:52	16:08	2.2	0.80	0.20	0.00	544	
								660	Average count
								174.53	SD
								0.26	CV

tion factor would have to range from approximately 4.13 to 1.95 on the same day to account for changes in beluga behavior and variability in the count (i.e., 484 × 4.132 ~ 2,000 and 1,024 × 1.953 ~ 2,000). Sampling designs aimed at reducing this variability will help in identifying the status of the stock and population trends.

We quickly concluded that distance sampling, a method that accounts for the fact that the probability of observation declines with distance, is not appropriate for surveying Bristol Bay belugas. To assess the applicability of distance sampling during the 2016 surveys, the data collector recorded sighting distances to each group of belugas. After the first two replicate surveys, we realized that virtually all belugas are observed in close proximity to shore (i.e., within about 100 m). Because there is so little variation in detection distance, there is not enough information (nor any need) to fit detection curves. The aircraft is positioned to provide the best view of shore and observers only need to scan the shoreline. Furthermore, belugas at this time of year are typically aggregated in large groups which are relatively easy to detect.

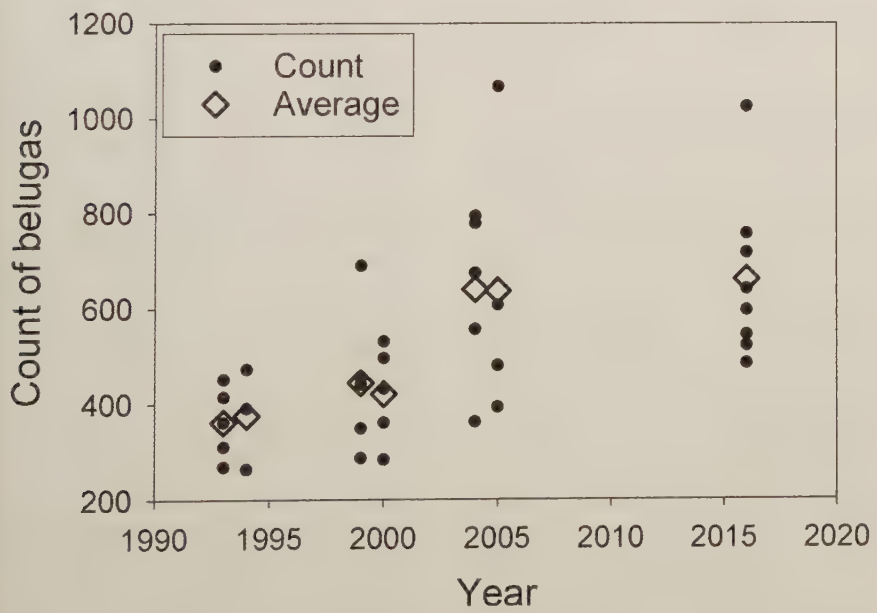

Figure 3.—Bristol Bay beluga counts and averages, 1993–2016.

We also conducted an informal experiment to assess if a correction factor is necessary for detection bias, also known as perception bias, which is defined as the bias due to observers not detecting belugas that are available to be counted. These corrections are typically estimated using multiple observers that record observations independently from one another, allowing the estimation of the probability that a group that is available to be detected is actually detected.

Because the sampling unit is a group of belugas, not individual belugas, we also wanted to know how detection varied by group size. For this informal experiment, the data recorder acted as the secondary observer and recorded the number and size of beluga groups that were missed by the primary observer on the same side of the aircraft. We found that all groups that were missed by the primary observer, but sighted by the secondary observer, had group sizes of one (n = 6) or two belugas (n = 2). No groups larger than two belugas were missed by the primary observer. Although groups of two or fewer belugas were the most common group size encountered (Fig. 4) and accounted for approximately 44% of all groups observed in 2011, these groups contributed little to the total count. Only 1.1% of the 5,480 belugas counted across all surveys occurred in group sizes of 1; likewise, only 1.1% occurred in group sizes of 2. Hence, even if the primary observer missed small groups quite often, which they

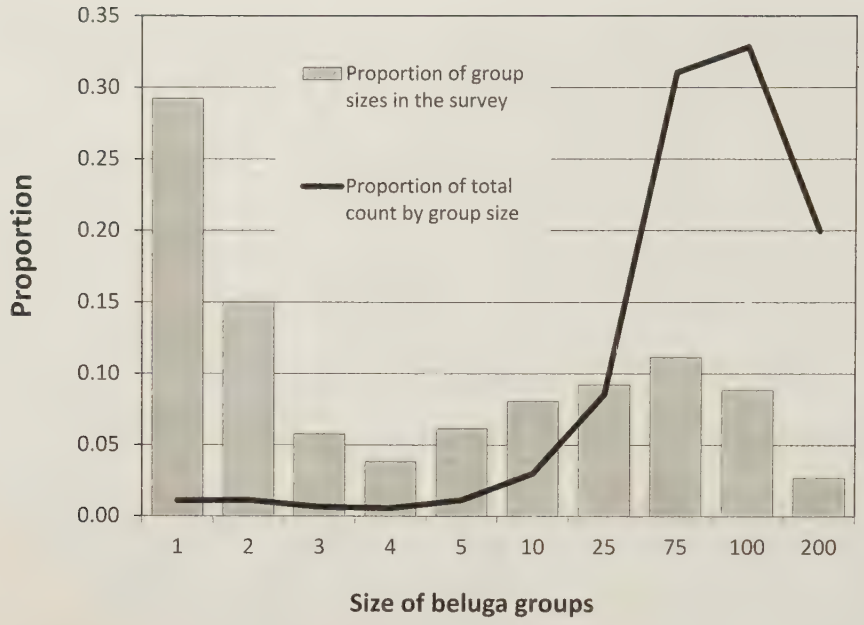

Figure 4.—Proportion of beluga group sizes (bars) observed and the proportion of the total count (line) contributed by each group size during aerial surveys in Bristol Bay, Alaska, 7–11 July 2016. Approximately 44% of all groups were composed of one or two belugas; however, only 2.2% of the total count occurred in groups of one or two belugas.

apparently do not, small groups probably do not contribute much to the overall count.

This is also the case for aerial surveys of belugas in Cook Inlet, Alaska, where double observers are used to estimate the probability of missing a group. Cook Inlet is a similar estuarine system as Bristol Bay and aerial surveys also follow the coastline (but also make more offshore flights; see Fig. 1 in Hobbs et al., 2015). During 2009–2016, the correction factor for missed groups ranged from 1.001 (in 2009) to 1.036 (in 2011; Shelden et al.[5]). Hence, in Cook Inlet, counts of belugas are typically corrected by less than 4% to account for groups that observers miss.

A more worrisome issue is how to count all the belugas in large groups. We conducted multiple counts of large groups and let observers identify which count was best, based upon observation conditions. If we look at multiple passes (i.e., counts) of the same group of belugas, we find that counts of group size sometimes varied by large amounts (Table 2). Although Table 2 includes counts that observers stated were not usable due to visibility concerns, this illustrates the uncertainty involved in counting large groups.

The fact that multiple passes are necessary to yield a count that observers think is valid also underscores the difficulty in counting large groups. We do not think that most of the variability in the count is due to our inability to count, but rather is due to beluga behavior. For example, if the diving behavior of individuals is correlated in such a way that many belugas dive or surface at the same time, then replicate counts of groups may exhibit large variation. Unfortunately, this cannot be assessed with the data available.

Because of the high variability in counts, both within and between surveys, we suggest that future surveys investigate how photo- (e.g., Lydersen et al., 2008; Terletzky and Ramsey, 2016) or video-based (e.g., Hobbs et al., 2000a, b) methods may be used to yield more precise counts or estimate real-time correction factors that account for beluga behavior at that moment, at least when counting large groups. Photos may allow for more precise counts and video may allow for the estimation of availability correction factors in real-time. For example, a commonly used correction factor (*CF*) is that of McLaren (1961):

$$CF = \frac{Dive\ interval}{Surface\ time + Observation\ time},$$

where the *dive interval* is the duration of time between surfacing events, *surface time* is the duration of surfacing events, and *observation time* is duration of time that a group is visible to observers. Laake et al. (1997) was able to estimate both surface intervals and dive intervals for groups of harbor porpoises, *Phocoena phocoena*, but only because they dove and surfaced as a group. Hobbs et al. (2000a) used video to estimate surface intervals for belugas in Cook Inlet, Alaska. Because belugas in Cook Inlet did not appear to dive and surface at the same time within groups and because individual belugas cannot be identified from the air, Hobbs et al. (2000b) could not estimate dive durations for individual belugas and had to use values from elsewhere. As in Cook Inlet, groups of belugas in Bristol Bay also do not dive and surface at the same time, so estimating dive intervals would be similarly difficult from an aircraft. We question the utility of using video to estimate surface intervals for beluga groups while assuming that the duration of dives is constant. Clearly, more research is needed to better estimate correction factors that account for changes in beluga behavior that occur during the aerial surveys.

A larger issue is whether it is better to improve aerial survey methods, including the development of improved correction factors, or to pursue completely different approaches for estimating abundance, such as genetic

[5]Shelden, K. E. W., R. C. Hobbs, C. L. Sims, L. Vate Brattström, J. A. Mocklin, C. Boyd, and B. A. Mahoney. 2017. Aerial surveys, abundance, and distribution of beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2016. AFSC Proc. Rep. 2017-09, 62 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle, WA 98115.

Table 2.—Counted group size by replicate count (aircraft pass) for 11 large groups of belugas.

	Group number										
Pass	1	2	3	4	5	6	7	8	9	10	11
1	111	283	271	210	192	236	67	65	69	433	270
2	60	552	390	262	202	279	62	47	54	341	285
3	43	302	295	247	246	226	76	52	74	403	289
4		332	230	300	244	289	96		90	360	
5			260	269	278	268	80			364	
6				271			96				
Range	68	269	160	90	86	63	34	18	36	92	19

mark-recapture. During 2004–11, the Alaska Department of Fish and Game (ADFG), working with the Alaska Beluga Whale Committee and Alaska Native beluga hunters, collected skin samples from the Bristol Bay stock using biopsy tips mounted on jab-sticks. Genetic markers from the skin biopsies were used to identify individual belugas and these data were analyzed in a mark-recapture framework. Using a POPAN Jolly-Seber model, abundance was estimated at 1,928 belugas (95% CI = 1,611–2,337; Citta et al., 2018). Most belugas were sampled in Kvichak Bay at a time when belugas are also known to occur in Nushagak Bay (Fig. 1). The pattern of genetic recaptures between bays and data from belugas with satellite transmitters (Citta et al., 2016a) indicated that belugas in the two bays regularly mix, suggesting the estimate of abundance likely applies to all Bristol Bay belugas. However, because it is likely that some belugas did not enter the sampling area during sampling, this estimate of abundance is best considered a minimum population size.

Results from the genetic mark-recapture study (N = 1,928 belugas) are consistent with the estimate from the 2016 aerial surveys, after commonly used correction factors were applied (N = 2,040 belugas). The mark-recapture approach has the advantage of not requiring correction factors, has valid confidence intervals, and allows the estimation of other parameters, such as survival. However, as it was implemented, the mark-recapture estimate required 10 years of data collection and survival rates were indistinguishable from a value of 1 (Citta et al., 2018). Although the mark-recapture approach could be implemented with just a few years of data collection, a much higher sampling intensity would be necessary, which would add additional disturbance to a method that already causes more disturbance than aerial surveys. Furthermore, the mark-recapture estimate was likely biased low (Citta et al., 2018), so the close correspondence in abundance between the mark-recapture study and aerial surveys was at least partially due to chance.

One last consideration is cost; the multi-year genetic-mark recapture project cost ~$260,000, while the aerial surveys in 2016 cost ~$53,000 and yielded a similar estimate of abundance. Although aerial survey costs would be higher if photos or video methods were implemented, it would still likely cost much less than a genetic mark-recapture project. That all the surveys flown in 2016 could be repeated four or five times in lieu of a single mark-recapture study is significant. We are not stating that another mark-recapture study in Bristol Bay is unwarranted because genetic approaches are constantly improving. In particular, the 'close-kin' mark-recapture technique of Bravington et al. (2016), which allows use of closely related animals to act as recaptures, may allow estimating abundance from a single sample year. However, until improved methods can be successfully implemented, we conclude that relatively simple aerial surveys are cost-effective for assessing the status of Bristol Bay belugas.

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Narwhal, *Monodon monoceros*, Catch Statistics in Greenland, 1862–2017

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Introduction

For the development of management advice on sustainable harvest levels of narwhals, *Monodon monoceros*, it is important that a complete history of removals by humans be reconstructed. Catch statistics for narwhals go back to 1862, but they are not complete and have never included the struck-but-lost whales. The completeness of the catch statistics has fluctuated not necessarily because of fluctuations in the harvest but because a large number of catches were not included in the records. This fraction of unreported catches and the number of struck-but-lost whales cannot be determined precisely, but estimates can be made using certain assumptions during limited periods.

A special problem with the catch statistics for Monodontids from West Greenland is that the catches that are taken from whale pods entrapped in the ice are included in the official catch statistics. It has been suggested that the occasional mortality in ice entrapments is part of the natural mortality (Siegstad and Heide-Jørgensen, 1994). To allow for analyses of removals without catches in ice entrapments, these are shown separately from the mortality genuinely caused by humans.

Narwhals have a complex population structure (Heide-Jørgensen et al., 2013) and for the assessment of the sustainability of the hunt it is critical that catches are correctly distributed on the stocks that are supplying the hunt in the various hunting areas. To the extent possible this compilation of the catch history follows the allocation of catches to hunting grounds that is used in the assessments (Watt et al., 2019). For assessment purposes it is furthermore important to be able to model the dynamics of populations using catch statistics that include options for corrections of unreported catches and whales that are struck-but-lost (Witting et al., 2019; Watt et al., 2019). It is important to maintain transparency in the corrections deployed to allow for different selections of the catch history in assessment models (Butterworth et al., 2002; Innes and Stewart, 2002; Alvarez-Flores and Heide-Jørgensen, 2004). The objective of this paper is to provide a complete catch record (1862–2017) that can be used in assessment models to provide sustainable catch levels for the indigenous narwhal hunt in Greenland.

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ABSTRACT—Information and statistics including trade statistics on catches of narwhals, Monodon monoceros, *in Greenland since 1862 are reviewed. Detailed statistics split by hunting grounds are missing for most of the years until 1993. For the northernmost area, Avanersuaq, only sporadic reporting exists. Based on statistics from the recent three decades, a time series is constructed for West Greenland with catches split into hunting grounds and corrected for underreporting assessed from purchases of whale skin called "mattak," for periods without catch records and from rates of struck-but-lost whales ("low," "medium," and "high option"). This reveals a time series of somewhat realistic catch levels from 1862 through 2017. Since 1993 catches have declined in West Greenland, especially in Uummannaq and Disko Bay where the decline is significant. In East Greenland, there has been an increase in catches from Ittoqqortoormiit and a decrease in catches from Tasiilaq from 1993 to 2017.*

Methods

This compilation utilizes statistics on narwhal catches in West Greenland between 1862 and 1891 from Winge (1902) and Anonymous (1944), between 1907 and 1934 from Heide-Jørgensen (1994) and Anonymous (1944), between 1954 and 1974 from Kapel (1977), between 1975 and 1990 from unpublished statistics from the Ministry of Greenland, and from 1993 to 2017 from "Piniarneq"[1]. For the periods 1862–1921, 1934–1948, and 1954–1963 catches were reported for the period 1 April through 31 March, but for the tabulation here all catches are allocated to the first of the years reported. This was done in order to compare data between calendar years, although some catches might belong to the following calendar year.

In addition to catch and hunter records, commercial records of narwhal mattak (whale skin) are also available from Midwest (Disko Bay) and Southwest Greenland (south of Disko Bay). Mattak was sold to factories that sold to markets for local consumption. In the three northernmost communities (Uummannaq, Upernavik, and Qaanaaq: Fig. 1A), most mattak is purchased by factory facilities providing sale figures that can be used to validate the numbers of harvested whales reported through "Piniarneq." Mattak not purchased by the factories were consumed by local hunters and

[1]"Piniarneq" refers to a booklet in which hunters note their catches; since 1993, it has provided catch figures. It also functions as an official hunting license and is reissued once a year upon submission of the completed records from the previous year.

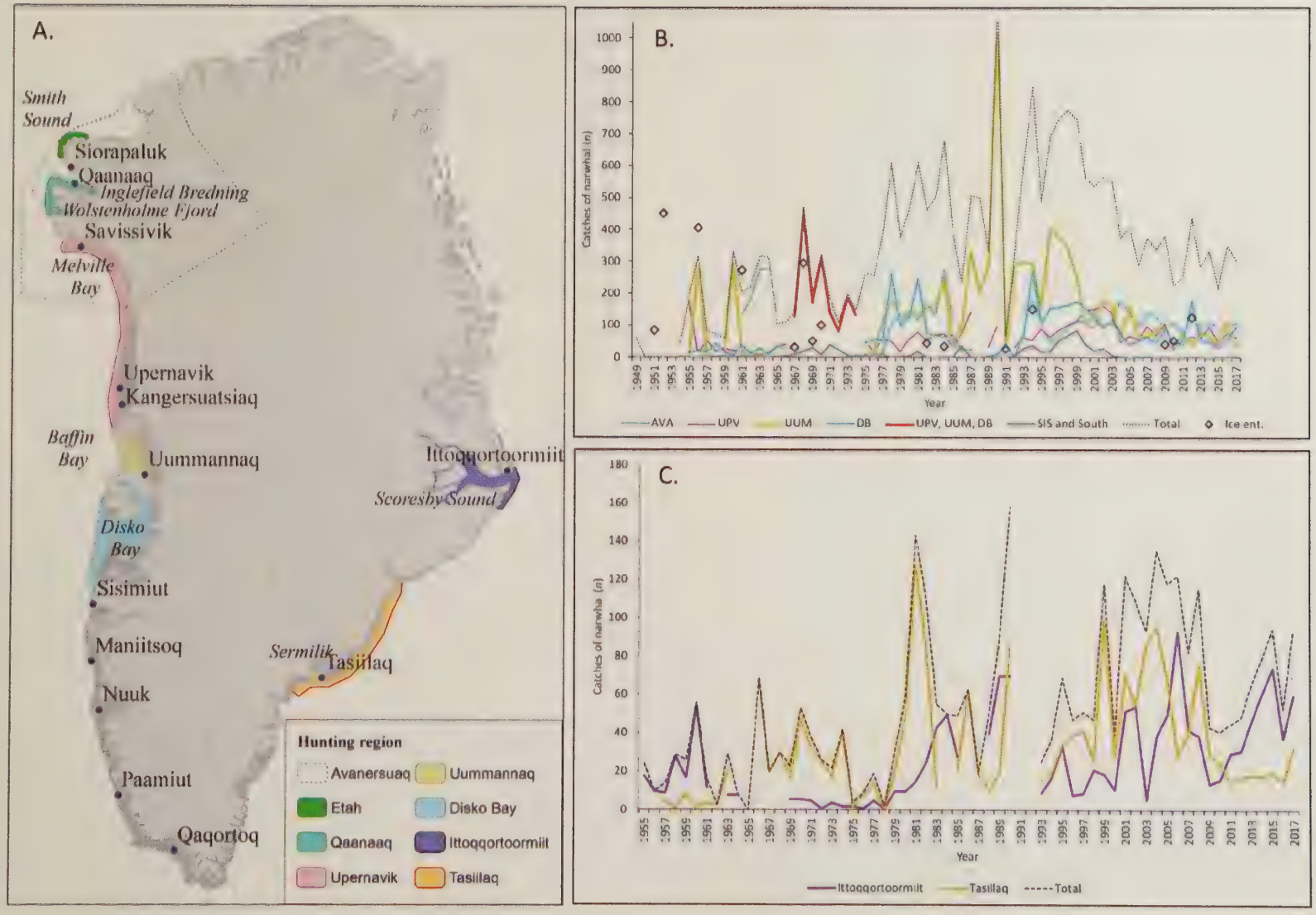

Figure 1.—A. Greenland with hunting regions, towns, settlements, and localities indicated. B. Catches of narwhals from official reports by municipality for 1954 to 2017, based on data presented in Table 2. Abbreviations: AVA=Avanersuaq, UPV=Upernavik, UUM=Uummanaaq, DB=Disko Bay (Illulissat, Kangaatsiaq, Qasigiannguit, Qeqertarsuaq, Aasiaat), SIS=Sisimiut, MAN=Maniitsoq, NUU=Nuuk, PAA-QAQ=Paamiut-Qaqortoq, SIS=Sisimiut, ICE ENT=Ice Entrapment. C. Reported catches of narwhals in Ittoqqortoormiit and Tasiilaq, East Greenland, from 1955 through 2017, based on data presented in Table 5.

residents in the community where the whales were taken.

Average mattak yield per whale was estimated from measurements of 40 narwhals harvested in Uummannaq in November 1993 where a mean of 132 kg mattak/whale (95% confidence limits: 111–152 kg) was obtained (Heide-Jørgensen[2]). Unfortunately, mattak purchases for narwhals and belugas, *Delphinapterus leucas*, were pooled until 1993.

Data on ice entrapments extracted from Siegstad and Heide-Jørgensen (1994), Heide-Jørgensen et al. (2002), Laidre et al. (2012), and unpublished data from 2012 (the Greenland Institute of Natural Resources (GINR)) were analyzed to subtract entrapment mortality from reported catches for the period 1984–2014.

In this compilation the uncorrected catch statistics (after 1962) are presented together with corrections referred to as "low," "medium," and "high options" (Heide-Jørgensen and Rosing-Asvid, 2002, and references therein). The "low" and "medium" options correct for biases caused by either an absence of catch reports from some municipalities during certain periods or by a general trend towards underreporting. The "high option" corrects the catches for an estimate of struck-but-lost whales in different hunting situations. The three options are intended for modeling different scenarios of the dynamics of the population to be used in assessments.

Results

West and North Greenland, 1862–1876

For the areas north of Sisimiut, annual catch data are available for 1862 through 1876 but only for belugas and narwhals combined. For these areas, Winge (1902) states that the catch was predominantly belugas, and Anonymous (1944) claims that, based on trade in narwhal tusks, narwhals only constituted about 20% of the catch.

[2]Heide-Jørgensen, M. P., Greenland Institute of Natural Resources, Nuuk. Personal commun., January, 1994.

Table 1.—Catches of narwhal in West Greenland between 1862 and 1934 compiled from Winge (1902). The catches are divided into three regions: Upernavik, Uummannaq, and Disko Bay. No data are available from other areas. Catches are corrected for the combined reporting of narwhals and belugas by assuming that 25% were narwhals (see text).

Year	Upernavik	Uummannaq	Disko Bay	Total
1862	29	4	45	78
1863	24	12	43	79
1864	42	30	70	142
1865	16	30	35	81
1866	32	20	72	124
1867	38	22	96	156
1868	17	11	55	83
1869	46	37	136	219
1870	23	80	106	209
1871	32	35	102	169
1872	22	46	103	171
1873	29	21	88	138
1874	32	13	106	151
1875	22	17	73	112
1876	24	23	80	127
1887–1888	32	38	117	187
1892–1893	31	42	102	175
1903–1909	33	35	70	138
1910–1919	50	62	112	224
1920–1924	46	42	74	162
1925–1929	43	55	58	156
1930–1934	43	53	87	183

Catch numbers are also available for some of the years from Sisimiut and south (1874–1890), but all those catches are considered to be belugas (Winge, 1902; Anonymous, 1944).

When comparing beluga and narwhal catches from 1954 to 1970 (Anonymous, 1953–71), the proportion of narwhals taken in North Greenland was about 25%, which is the correction factor applied here (Table 1). Catches were fairly constant in Upernavik (mean = 29/yr, SD 9) but varied in Uummannaq (mean = 27/yr, SD 19) and Disko Bay (mean = 81/yr, SD 28) for the period 1862–1876 (Table 1). No catch information exists from Thule[3], and no specific information on ice entrapments of narwhals exists from this period. No catch data have been located for the period 1876–87.

West and North Greenland, 1887–1934

Only sporadic statistics on average catches over periods and areas are available from Anonymous (1944) (Table 1). Catches given as averages for the areas north of Sisimiut, where both belugas and narwhals were pooled (Anonymous, 1944), were assumed to be comprised of 25% narwhals. The catches for this period seem slightly higher than for the previous period as the weighted (weight = number of years) averages are 42/yr (SD 17) for Upernavik, 49/yr (SD 26) for Uummannaq, and 87/yr (SD 51) for Disko Bay. No catch information is available from Thule for this period, but Vibe (1950) estimated that around 125 narwhals were taken annually in Thule in the late 1930's, and statistics on trade in narwhal tusks indicate large catches from 1938 (Reeves and Heide-Jørgensen, 1994).

The ice entrapment records include incidents from Disko Bay, Uummannaq, and Upernavik but only the reports from 1915 are specified as narwhals; the others may include both belugas and narwhals (Siegstad and Heide-Jørgensen, 1994). The entrapment in 1915 included more than 1,100 narwhals in Disko Bay (Porsild, 1918; Anonymous, 1944), but these numbers apparently did not appear in the catch statistics (Table 1).

West and North Greenland, 1949–54

Only fragmentary information on the catches exists for this period (Fig.

[3]Thule was previously a trading station in North Greenland. The place name Thule in this compilation is used until 1950 and covers catches taken in northern Greenland. From 1951 to present, the county name Avanersuaq is used for northern Greenland. The name covers catches recorded for the community Qaanaaq and the settlements Savissivik and Siorapaluk.

1B, Table 2). Catches reported in 1949 (Prime Minister's Second Department, 1951) and 1954 seem unrealistically low compared to both earlier and later catch estimates. During this period all catches in Thule/Avanersuaq[3] are assumed to be from the Inglefield Bredning stock of narwhals, as hunters were not able to travel long distances in kayaks to catch narwhals from other areas.

West and North Greenland, 1955–74

The statistics for the period 1954–74 probably provide a fairly realistic picture of the level of narwhal hunting except for Avanersuaq, which only reported catches for 1961–64 (Fig. 1B, Table 2). For 1961–64, reported catches for Qaanaaq are used directly with no corrections and the average of the period (= 217 catches) is used to estimate a linear decline in catches from 217 catches in 1965 to 120 catches in 1977, which is the mean catch in 1978–81. Bruemmer[4] estimated that around 90–120 narwhals were taken annually around 1970.

Catch records cannot be separated into municipalities for the period 1967–74 and corrections for unreported catches can therefore not be assigned to specific areas (Fig. 1B, Table 2). For periods with compatible data there is a trend for an increase in catches especially in the Disko Bay area as the distribution of catches changed from 1955–60, when Upernavik took 44% of the narwhals, Uummannaq took 35%, and Disko Bay took 21%, to 1978–82 when Upernavik declined to 15%, Uummannaq increased to 43%, and Disko Bay increased to 41%. Ice entrapments in Uummannaq and Upernavik in 1956 and in Uummannaq in 1961 are subtracted from the catch report from the previous year.

[4]Bruemmer, F. 1971. Notes on sea mammals, Thule District, Greenland. Report to the Arctic Biological Station Fisheries Research Board of Canada. Ste. Anne de Bellevue, Quebec. Unpubl. manuscr., 29 p.

West and North Greenland, 1975–85

Avanersuaq started to report a realistic level of catches in 1978, but for the period 1965–74 catches have been corrected for the trade in mattak. The large amount of mattak purchased in Avanersuaq (22 t) in 1984 is reflected in the catch statistics for narwhals and is not sustained by the reported catch of 21 belugas (Heide-Jørgensen and Rosing-Asvid, 2002; Table 3). The period (1975–85) had few reported catches in Sisimiut. Narwhal entrapments are reported for Disko Bay and Uummannaq during this period (Siegstad and Heide-Jørgensen, 1994) (Fig. 1B, Table 2).

West and North Greenland, 1986–92

The catch reporting system deteriorated during this period while the economic value of the mattak increased. No official catch statistics were received in any of these years from Avanersuaq and Sisimiut municipality. The hunt in Avanersuaq is supplied by narwhals from three different stocks: the Inglefield Bredning stock is the largest contributor, the Melville Bay stock provides narwhals to the southern community (Savissivik) in Avanersuaq, and the Smith Sound stock provides only a few narwhals (Fig. 1A; Watt et al., 2019). Catches from the Inglefield Bredning stock can be estimated from the linear trend in catches in Avanersuaq (after subtraction of catches in Melville Bay) from 1983–85 to 1993–95. Trade statistics on purchases of mattak do not distinguish between narwhals and belugas, and assumptions about the proportion of narwhals are required if the trade statistics are to be used for correcting narwhal catch statistics. No official statistics are available for 1991 and 1992 (Fig. 1B, Table 2). No ice entrapments are reported for this period.

West and North Greenland, 1993–2017

In 1993 the new catch reporting system "Piniarneq" started to provide data. It operates with hunting seasons, but data are compiled following calendar years. Since 1996, the hunters have also been asked to fill out "special reports[5]" that provide more detailed information about the hunt including hunting dates and locality, hunting method, and length and sex of the whales. Yet, in some years, only a small fraction of the catches was documented in the "special reports," but in recent years (2005–17), after the installation of quotas in 2004, the "special reports" are considered the most complete source of catch statistics. Data from the "special reports" are used to split catches between the hunting regions in Avanersuaq (Qaanaaq, Siorapaluk, Savissivik).

Data on mattak trade of narwhals are available for Avanersuaq, Upernavik, Uummannaq, and Disko Bay (Table 3). When calculating the number of whales required to sustain the mattak purchases, under the assumption of 132 kg/narwhal, there is on average a reporting of three times as many catches as needed to sustain the purchases of mattak in Upernavik and Uummannaq during 1994–99. The only exception is 1997 in Upernavik where the catches reported were approximately half of what is needed to sustain the mattak purchases. In Avanersuaq, the reported catches are only slightly larger than the purchases of mattak but this varies between years. A large proportion of mattak is consumed locally in Qaanaaq, Siorapaluk, and Savissivik and the reported catches seem therefore to underestimate the actual hunting level.

No reliable data exist on the trade in narwhal mattak from the Disko Bay area, Sisimiut, or south of Sisimiut. Most mattak in these areas is sold directly by the hunters and no statistics are kept on the amount being traded.

From 1 July 2004, a quota system for narwhal hunting in West Greenland was instituted, and the decline in catches in 2004 is partly due to the new catch limits. Five ice entrapments are

[5]The "special reports" are called "særmeldeskemaer" in Danish.

Table 2.—Catches of narwhals from official reports by municipality with corrections for underreporting in parentheses (see text) from 1954 to 2017. AVA=Avanersuaq (until 1950 called Thule), UPV=Upernavik, UUM=Uummanaaq, DB=Disko Bay (Ilulissat, Kangaatsiaq, Qasigiannguit, Qeqertarsuaq, Aasiaat), SIS=Sisimiut, MAN=Maniitsoq, NUU=Nuuk, PAA-QAQ=Paamiut-Qaqortoq, ICE ENT=Ice Entrapment. Numbers in square brackets are from "special reports." Numbers in italics are catch numbers for the areas UPV, UUM, DB, and for SIS, NUU, MAN, PAA-QAQ. Data were compiled from Prime Minister's Second Department (1951), Kapel (1977), Kapel and Larsen (1984), Kapel (1985), Born and Kapel (1986), and Born (1987).

YEAR	AVA	UPV	UUM	DB	SIS	MAN	NUU	PAA-QAQ	TOTAL	ICE ENT
1949	38	16	1	6					61	
1950										
1951										85 DB
1952										450 DB
1954			*45*		1			1	47	
1955		179	2	14					195	
1956		15	282	21					318	156 UPV, 250 UUM
1957		55	11	15					81	
1958		24	3	45		1			73	
1959		32	8	16				1	57	
1960		25	296	7	1	1	1	1	332	
1961	134	25	5	38				1	203	272 UUM
1962	182	17	11	12				1	223	
1963	275	10	3	29					317	
1964	275	17	11	11					314	
1965		33	37	33	1	1			105	
1966		39	23	43		3	2		110	
1967			*131*				*9*		140	31 DB
1968			*454*				*18*		472	161 DB, 50 UPV, 84 UUM
1969			*174*				*30*		204	Some DB, 50 UPV
1970			*313*				*9*		322	100 DB
1971			*146*				*40*		186	
1972			*84*				*23*		107	
1973			*191*				*8*		199	
1974	8		*136*				*3*		147	
1975	1	54	11	44		6		1	266 (149)	
1976	9	22	27	57					256 (141)	
1977	16	62	113	53	8	1			387 (134)	
1978	110	56	183	262		1			612	
1979	120	22	132	100			3		377	
1980	130	61	146	120		4	1		462	
1981	118	83	140	249			18	1	609	
1982	164	59	162	76					461	45 DB
1983	135 (25)	72 (30)	164	68 (10)					504 (65)	
1984	274	80	245	66 (15)	1				681 (15)	35 UUM
1985	115 (115)	34 (20)	39	67		1			391 (135)	
1986		81	97	23		36			237	
1987		145	334	25			1		505	
1988			206						500 (294)	
1989		37	288	2			5		332	
1990		100 (73)	1,019	11					1,203 (73)	
1991			27	> 40					> 67	27 UUM
1992		37	288	2			5		332	
1993	144	66	301	75	10	6	4	8	614	
1994	183	59	297	268	6	14	7	11	845	150 DB
1995	107	94	159	108	4	5	8		485	
1996	45	69	405	154	10	4	2	2	691	
1997	66	90	381	156	13	5	9	26	746	
1998	94	105	344	163	21	18	6	24	775	
1999	115	119	253	174	28	24	17	15	745	
2000	109	150	106	155	27	8	0	6	561	
2001	145	155	95	119	1	2	15	3	535	
2002	94	164	180	97	12	11	3	2	563	
2003	113	146	174	114	4	0	2	2	555	
2004	178	53	67	73	2	1	0	0	374	
2005	137 [70]	71 [74]	161 [137]	39 [47]	0	0	0	0	408 [328]	
2006	99 [94]	62 [58]	72 [55]	53 [4]	1	2	0		289 [211]	
2007	139 [21]	102 [17]	67 [52]	63 [56]	0	2	0	1	374 [146]	
2008	[129]	[74]	[87]	[47]	[0]	[0]	[0]	[0]	[337]	
2009	[90]	[110]	[91]	[88]	[0]	[0]	[0]	[1]	[380]	41 in Qaanaaq
2010	[108]	[30]	[42]	[45]	[0]	[0]	[0]	[0]	[225]	53 in Qaanaaq
2011	[74]	[60]	[77]	[39]	[0]	[0]	[0]	[1]	[251]	
2012	[144]	[70]	[42]	[179]	[0]	[0]	[0]	[1]	[436]	125 at Kangersuatsiaq
2013	[90]	[64]	[78]	[50]	[0]	[0]	[0]	[1]	[283]	
2014	[114]	[101]	[69]	[50]	[0]	[0]	[0]	[0]	[334]	
2015	[92]	[54]	[42]	[29]	[0]	[0]	[1]	[0]	[218]	
2016	[93]	[79]	[120]	[55]	[0]	[0]	[1]	[0]	[348]	
2017	[108]	[67]	[33]	[95]	[0]	[2]	[0]	[0]	[305]	

Table 3.—Purchases (in tons) of narwhal mattak (1965–1992 data from Heide-Jørgensen (1994); 1994–1999 data from Greenland Statistics). Mattak data for 1965–1992 was for narwhals and belugas combined, but after 1993 only narwhal data are shown. The factory ship mainly operated in Uummannaq and Disko Bay.

Year	Avanersuaq	Upernavik	Uummannaq	Disko Bay	Factory ship	Total
1965	1.5					1.5
1966	5.3	0.1				5.4
1967	3.9	0.1				4.0
1975		2.9				2.9
1976	11	0.4				11.4
1977	14	9.1				23.1
1978	6	2.8				8.8
1979	14					14
1980	14					14
1981	26.5	25.0				51.5
1982	24.0	21.2				45.2
1983	12.8	21.1				33.9
1984	21.9	20.7				42.6
1985		5.8				5.8
1986		1.7				1.7
1987		32.6	4.4	0		37
1988	2.4	27.3	7.3	4.9		41.9
1989		19.3	31.0	0.8		51.1
1990	9.2	18.5	63.6	18.7		110.0
1991	15.1	26.1	29.4	1.4		72.0
1992	12.2	46.3	13.3	7.5		79.3
1994	12.6	3.0	31.6	<0.1		47.3
1995	10.7	9.9	4.8	<0.1		25.5
1996	4.3	6.1	25.5	<0.1		36.0
1997	10.6	21.1[1]	19.5	<0.1		51.3
1998	14.1	3.4[2]	6.5		8.5	32.5
1999	12.4	1.9		<0.1	10.3	24.7

[1]Including 0.29 tons purchased in Savissivik.
[2]Including 2.4 tons purchased in Savissivik.

reported during this period (Siegstad and Heide-Jørgensen, 1994; Heide-Jørgensen et al., 2002; Laidre et al., 2012), and one entrapment where 125 narwhals were taken occurred 10 km west of the hamlet of Kangersuatsiaq, Upernavik, in February 2012 (GINR[6]).

Construction of Time Series for West Greenland From 1862 Through 2017

Utilization of whales in Inglefield Bredning by Inughuit (the people living in Avanersuaq) during the 19th century probably included few narwhals because Inughuit did not have access to rifles and they were no longer using kayaks. However, expeditions and foreign whalers sold guns and ammunition to Inughuit and this must eventually have increased the hunting pressure on narwhals during the 19th century. The wintering of several of Robert E. Peary's large expeditions in the area around the turn of the century could also have increased the hunting pressure on narwhals in Inglefield Bredning. Finally, the reintroduction of kayaks after 1865 also added to the hunting pressure.

To account for the lack of statistics the catches for Inglefield Bredning was arbitrarily set to 25 whales per year for 1862–1899 and to 50 for 1900–34. From 1935 to 1960 catches increased linearly from 50 to 134 (catch reported in 1961) in Inglefield Bredning. This gives values about half of what Vibe (1950) estimated for the locality in 1939–40 but considerably larger than the 38 narwhals reported to be taken in 1949 (Table 2; Prime Minister's Second Department, 1951).

For the other areas, catches were created as the average of 5 years before and 2 years after the periods 1877–1886 and 1889–1891, respectively. Catches for the period 1894–1902 were set to the average of 5 years before and after that period. The period 1935–48 was constructed as linear extrapolations of the catches before and after the period. Catches for the period for 1949–54 were calculated as the average of the catches for 1955–58 (excluding ice entrapments), again assuming that catches were larger than reported in 1949 (Prime Minister's Second Department, 1951).

During 1949–75 catches were not available per municipality or hunting ground and coarse assumptions about underreporting and splitting on hunting grounds are needed to reconstruct the catches for that period. Catches during 1975–77 include an overall correction for underreporting.

A "low option" for catches during 1984–2005 is provided by correcting the reported catches with estimates for years with missing data calculated as averages of three years before and after the missing year (Table 4). Catches from the stocks in Inglefield Bredning, Melville Bay, and Uummannaq were corrected for underreporting assessed from the purchases of mattak.

For the period 1965–92, mattak from reported harvests of belugas were subtracted, assuming average mattak yields of 70 kg/beluga (Heide-Jørgensen and Rosing-Asvid, 2002). The remaining mattak is assumed to be from narwhals, and the catch is calculated on the basis of 132 kg/narwhal (Table 3). For Uummannaq, all mattak purchases during 1987–92 were assumed to be from narwhals. Catches of belugas are the only alternative source of mattak and low levels of beluga catches were reported for Uummannaq during that period.

For the years after 1992, mattak purchases were separated by species, and estimates of narwhal catches needed to sustain mattak purchases were made per area. Narwhal harvested during ice entrapments were subtracted because ice entrapments are considered part of natural mortality and should be excluded from hunting mortality (Siegstad and Heide-Jørgensen, 1994). Catches from Savissivik are assumed to be taken in the Melville Bay area and are therefore allocated to the Melville Bay stock together with all catches from Upernavik.

For Avanersuaq for 1995–99, a "low option" and a "medium option" is the reported catches. For Disko Bay a "medium option" would be to correct for the generally low reporting between 1986 and 1992 by using the average of the periods 1978–85 and 1993–2000 (average = 156).

A "high option" is to correct the catches for whales that are struck-but-lost. It is generally assumed that the

[6]GINR, Nuuk, March 2012. Unpubl. data.

Table 4.—Estimated number of narwhals caught annually from 1862 through 2017 by stock. Catches during 1877–1886 and 1889–1891 were created as the average of five years before and two years after the period. Catches between 1894 and 1902 were set to the average of five years before and after the period. The period 1935–1948 was constructed as linear extrapolations of the catches before and after the period. Catches for the period for 1949–1954 and 1959–1960 were calculated as the average of the catches for the period 1955 to 1958 (minus ice entrapments). Catches for Inglefield Bredning was arbitrarily set to 25 whales per year for 1862 to 1899 and to 50 for 1900 to 1934. From 1935 to 1960 catches were increased linearly from 50 to 134 in Inglefield Bredning. For 1959 to 1974 catches were distributed between Upernavik, Uummannaq, and Disko Bay in proportion to the relative change in catch levels before and after that period.

After 1983 catches in Savissivik in Avanersuaq are allocated to the Upernavik–Melville Bay stock (for stock delineation see Watt et al., 2019) together with catches from Upernavik municipality. From 1993 to 2010 catches in Siorapaluk are subtracted from the catches in Inglefield Bredning as they are assumed to be from the Smith Sound stock; however in 2011 this practice was changed to allocate any catches with location data north of Siorapaluk to the Smith Sound. Catches from all areas south of Disko Bay are assumed to come from the Disko Bay stock. Narwhals harvested in ice entrapments are not included in the catches. Values for years with no catch reporting are constructed as the average of three years before and after the missing year. In the "low option" catches from Inglefield Bredning and Melville Bay are corrected for under-reporting needed to sustain the purchases of mattak. The "medium option" applies only for Disko Bay and correct for the generally low reporting between 1986 and 1992 by using the average of the periods 1978–1985 and 1993–2000. Before 1950 all catches under the "high option" are corrected for a loss rate of 5%. After 1950, catches in Inglefield Bredning and Smith Sound under the "high option" are corrected for a 5% loss rate, catches in Melville Bay are corrected for a 15% loss rate, and catches in Uummannaq and Disko Bay are corrected for a 30% loss rate. The quality of the data is assessed based on the number of corrections needed where LQ = low quality, MQ = moderate quality, and R = reliable.

		Smith Sound			Inglefield Bredning			Melville Bay			Uummannaq			Disko Bay and south		
Stock Year	Quality of data	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
1862	LQ				25	25	26	29	29	30	4	4	4	45	45	47
1863	LQ				25	25	26	24	24	25	12	12	13	43	43	45
1864	LQ				25	25	26	42	42	44	30	30	32	70	70	74
1865	LQ				25	25	26	16	16	17	30	30	32	35	35	37
1866	LQ				25	25	26	32	32	34	20	20	21	72	72	76
1867	LQ				25	25	26	38	38	40	22	22	23	96	96	101
1868	LQ				25	25	26	17	17	18	11	11	12	55	55	58
1869	LQ				25	25	26	46	46	48	37	37	39	136	136	143
1870	LQ				25	25	26	23	23	24	80	80	84	106	106	111
1871	LQ				25	25	26	32	32	34	35	35	37	102	102	107
1872	LQ				25	25	26	22	22	23	46	46	48	103	103	108
1873	LQ				25	25	26	29	29	30	21	21	22	88	88	92
1874	LQ				25	25	26	32	32	34	13	13	14	106	106	111
1875	LQ				25	25	26	22	22	23	17	17	18	73	73	77
1876	LQ				25	25	26	24	24	25	23	23	24	80	80	84
1877	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1878	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1879	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1880	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1881	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1882	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1883	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1884	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1885	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1886	LQ				25	25	26	28	28	29	28	28	29	98	98	103
1887	LQ				25	25	26	32	32	34	38	38	40	117	117	123
1888	LQ				25	25	26	32	32	34	38	38	40	117	117	123
1889	LQ				25	25	26	29	29	30	35	35	37	105	105	110
1890	LQ				25	25	26	29	29	30	35	35	37	105	105	110
1891	LQ				25	25	26	29	29	30	35	35	37	105	105	110
1892	LQ				25	25	26	31	31	33	42	42	44	102	102	107
1893	LQ				25	25	26	31	31	33	42	42	44	102	102	107
1894	LQ				25	25	26	31	31	33	36	36	38	87	87	91
1895	LQ				25	25	26	31	31	33	36	36	38	87	87	91
1896	LQ				25	25	26	31	31	33	36	36	38	87	87	91
1897	LQ				25	25	26	31	31	33	36	36	38	87	87	91
1898	LQ				25	25	26	31	31	33	36	36	38	87	87	91
1899	LQ				25	25	26	31	31	33	36	36	38	87	87	91
1900	LQ				50	50	53	31	31	33	36	36	38	87	87	91
1901	LQ				50	50	53	31	31	33	36	36	38	87	87	91
1902	LQ				50	50	53	31	31	33	36	36	38	87	87	91
1903	LQ				50	50	53	33	33	35	35	35	37	70	70	74
1904	LQ				50	50	53	33	33	35	35	35	37	70	70	74
1905	LQ				50	50	53	33	33	35	35	35	37	70	70	74
1906	LQ				50	50	53	33	33	35	35	35	37	70	70	74
1907	LQ				50	50	53	33	33	35	35	35	37	70	70	74
1908	LQ				50	50	53	33	33	35	35	35	37	70	70	74
1909	LQ				50	50	53	33	33	35	35	35	37	70	70	74
1910	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1911	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1912	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1913	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1914	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1915	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1916	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1917	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1918	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1919	LQ				50	50	53	50	50	53	62	62	65	112	112	118
1920	LQ				50	50	53	46	46	48	42	42	44	74	74	78
1921	LQ				50	50	53	46	46	48	42	42	44	74	74	78
1922	LQ				50	50	53	46	46	48	42	42	44	74	74	78
1923	LQ				50	50	53	46	46	48	42	42	44	74	74	78
1924	LQ				50	50	53	46	46	48	42	42	44	74	74	78
1925	LQ				50	50	53	43	43	45	55	55	58	58	58	61

Table continued.

Table 4.—*Continued.*

Stock Year	Quality of data	Smith Sound			Inglefield Bredning			Melville Bay			Uummannaq			Disko Bay and south		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
1926	LQ				50	50	53	43	43	45	55	55	58	58	58	61
1927	LQ				50	50	53	43	43	45	55	55	58	58	58	61
1928	LQ				50	50	53	43	43	45	55	55	58	58	58	61
1929	LQ				50	50	53	43	43	45	55	55	58	58	58	61
1930	LQ				50	50	53	43	43	45	53	53	56	87	87	91
1931	LQ				50	50	53	43	43	45	53	53	56	87	87	91
1932	LQ				50	50	53	43	43	45	53	53	56	87	87	91
1933	LQ				50	50	53	43	43	45	53	53	56	87	87	91
1934	LQ				50	50	53	43	43	45	53	53	56	87	87	91
1935	LQ				53	53	56	42	42	44	50	50	53	83	83	87
1936	LQ				56	56	59	41	41	43	48	48	50	78	78	82
1937	LQ				59	59	62	40	40	42	45	45	47	74	74	78
1938	LQ				62	62	65	39	39	41	42	42	44	70	70	74
1939	LQ				66	66	69	38	38	40	39	39	41	65	65	68
1940	LQ				69	69	72	37	37	39	37	37	39	61	61	64
1941	LQ				72	72	76	36	36	38	34	34	36	57	57	60
1942	LQ				75	75	79	36	36	38	31	31	33	52	52	55
1943	LQ				78	78	82	35	35	37	28	28	29	48	48	50
1944	LQ				81	81	85	34	34	36	26	26	27	44	44	46
1945	LQ				84	84	88	33	33	35	23	23	24	39	39	41
1946	LQ				87	87	91	32	32	34	20	20	21	35	35	37
1947	LQ				90	90	95	31	31	33	17	17	18	31	31	33
1948	LQ				94	94	99	30	30	32	15	15	16	26	26	27
1949	LQ				97	97	102	29	29	30	12	12	13	22	22	23
1950	LQ				100	100	105	29	29	30	12	12	13	22	22	23
1951	LQ				103	103	108	29	29	33	12	12	16	22	22	29
1952	LQ				106	106	111	29	29	33	12	12	16	22	22	29
1953	LQ				109	109	114	29	29	33	12	12	16	22	22	29
1954	LQ				112	112	118	29	29	33	12	12	16	22	22	29
1955	LQ				115	115	121	23	23	26	2	2	3	14	14	18
1956	LQ				118	118	124	15	15	17	32	32	42	21	21	27
1957	LQ				122	122	128	55	55	63	11	11	14	8	8	10
1958	LQ				125	125	131	24	24	28	3	3	4	46	46	60
1959	LQ				128	128	134	25	25	29	11	11	14	21	21	27
1960	LQ				131	131	138	24	24	28	12	12	16	24	24	31
1961	MQ				134	134	141	29	29	33	15	15	20	26	26	34
1962	MQ				182	182	191	12	12	14	7	7	9	12	12	16
1963	MQ				275	275	289	16	16	18	10	10	13	16	16	21
1964	MQ				275	275	289	16	16	18	11	11	14	18	18	23
1965	LQ				210	210	221	35	35	40	25	25	33	40	40	52
1966	LQ				203	203	213	36	36	41	28	28	36	47	47	61
1967	LQ				196	196	206	33	33	38	28	28	36	50	50	65
1968	LQ				189	189	198	50	50	58	46	46	60	83	83	108
1969	LQ				182	182	191	37	37	43	37	37	48	82	82	107
1970	LQ				175	175	184	61	61	70	66	66	86	99	99	129
1971	LQ				168	168	176	39	39	45	46	46	60	103	103	134
1972	LQ				161	161	169	21	21	24	27	27	35	60	60	78
1973	LQ				154	154	162	46	46	53	64	64	83	92	92	120

Table continued.

loss rate was low before 1950, where all catches have been corrected by 5% to account for some losses. No studies of losses have been conducted in Greenland, but inferences can be made from studies in other areas. In Avanersuaq local hunting rules requires the attachment of hand-harpoons on the whales before they can be shot. This severely reduces the loss rate, and a loss rate of 5% is arbitrarily applied to the catches in Inglefield Bredning to account for both whales that are struck-but-lost and calves that are separated from mothers.

Catches from the Melville Bay stock, however, come from hunting in both Avanersuaq and Upernavik, which does not require the use of hand-harpoons. Roughly half the whales from the Melville Bay stock are taken under the harpoon requirement (5% loss rate) and the other half is taken in ice-edge and open-water situations. For narwhal hunting in open water in Canada, Weaver and Walker (1988) reported loss rates between 32% and 55% or catch correction factors of 1.5–2.2. Roberge and Dunn (1990) reported catch correction factors for narwhals in Canada to range from 1.11 in open water to 1.41 at the ice crack and 1.56 at the floe edge or ice edge.

For Greenland, it is assumed under the "high option" that a catch correction factor of 1.30 covers both the open-water hunt and the hunt from ice cracks and the ice edge. An exception is for the Melville Bay-Upernavik area where a factor of 1.15 is used. The correction factor of 1.30 also covers the open-water hunt in late autumn just before freeze-up, which is a type of hunt where loss rates have not been estimated. If anything, the correction factor of 1.30 applied here is downward biased and might underestimate hunting losses. Thus, after 1950, catches in Inglefield Bredning and Smith Sound are under the "high option" and are corrected for a 5% loss rate, catches in Melville Bay are corrected for a 15% loss rate, and catches in Uummannaq and Disko Bay are corrected for a 30% loss rate.

Table 4.—*Continued.*

Stock Year	Quality of data	Smith Sound			Inglefield Bredning			Melville Bay			Uummannaq			Disko Bay and south		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
1974	LQ				147	147	154	30	30	35	47	47	61	64	64	83
1975	LQ				140	140	147	54	54	62	11	11	14	51	51	66
1976	LQ				133	133	140	22	22	25	27	27	35	57	57	74
1977	LQ				126	126	132	62	62	71	113	113	147	31	31	40
1978	MQ				110	110	116	56	56	64	183	183	238	263	263	342
1979	MQ				120	120	126	22	22	25	132	132	172	103	103	134
1980	MQ				130	130	137	61	61	70	146	146	190	125	125	163
1981	MQ				160	160	168	83	83	95	140	140	182	268	268	348
1982	MQ				164	164	172	59	59	68	162	162	211	76	76	99
1983	MQ				135	135	142	72	72	83	164	164	213	68	68	88
1984	MQ				274	274	288	80	80	92	210	210	273	67	67	87
1985	MQ				115	115	121	34	34	39	39	39	51	68	68	88
1986	LQ				165	165	173	81	81	93	97	97	126	59	156	203
1987	LQ				155	155	163	145	145	167	334	334	434	26	156	203
1988	LQ				145	145	152	85	85	98	226	226	294	35	156	203
1989	LQ				136	136	143	37	37	43	288	288	374	7	156	203
1990	LQ				126	126	132	127	127	146	1019	1019	1325	11	156	203
1991	LQ				116	116	122	90	90	104	223	223	290	40	156	203
1992	LQ				106	106	111	37	37	43	288	288	374	7	156	203
1993	R	4	4	4	104	104	109	102	102	117	301	301	391	103	103	134
1994	R	2	2	2	90	90	95	150	150	173	297	297	386	156	156	203
1995	R	0	0	0	88	88	92	113	113	130	159	159	207	125	125	163
1996	R	0	0	0	37	37	39	77	77	89	405	405	527	172	172	224
1997	R	4	4	4	54	54	57	98	98	113	381	381	495	209	209	272
1998	R	3	3	3	68	68	71	128	128	147	344	344	447	227	227	295
1999	R	17	17	18	87	87	91	130	130	150	253	253	329	258	258	335
2000	R	20	20	21	85	85	89	154	154	177	106	106	138	196	196	255
2001	R	30	30	32	98	98	103	172	172	198	95	95	124	140	140	182
2002	R	23	23	24	58	58	61	177	177	204	180	180	234	125	125	163
2003	R	35	35	37	66	66	69	158	158	182	174	174	226	121	121	157
2004	R	52	52	55	111	111	117	68	68	78	67	67	87	76	76	99
2005	R	52	52	55	79	79	83	77	77	89	161	161	209	39	39	51
2006	R	19[1]	19	20	55[1]	55	58	80[2]	80	92	72[3]	72	94	56[3]	56	73
2007	R	0[4]	0	0	134[4]	134	141	107[5]	107	123	67[3]	67	87	66[3]	66	86
2008	R	7	7	7	122	122	128	92	92	106	87	87	113	47	47	61
2009	R	6	6	6	84	84	88	136	136	156	91	91	118	89	89	116
2010	R	9	9	9	99	99	104	40	40	46	42	42	55	45	45	59
2011	R	2	2	2	53	53	56	79	79	91	77	77	100	40	40	52
2012	R	3	3	3	128	128	134	83	83	95	42	42	55	55	55	72
2013	R	0	0	0	83	83	87	71	71	82	78	78	101	51	51	66
2014	R	0	0	0	102	102	107	113	113	130	69	69	90	50	50	65
2015	R	0	0	0	75	75	79	71	71	82	42	42	55	29	29	38
2016	R	0	0	0	81	81	85	91	91	105	120	120	156	56	56	73
2017	R	0	0	0	108	108	113	92	92	106	33	33	43	97	97	126

[1]Based on "special reports."
[2]Based on "special reports" from Savissivik and "Piniarneq" from Upernavik.
[3]Based on "Piniarneq"—"special reports" numbers are too low.
[4]Catches from Siorapaluk are all assumed to be from Inglefield Bredning.
[5]Includes 5 catches reported from Savissivik ("special reports").

East Greenland

The reported catches in East Greenland during 1993–2017 averaged 35 whales annually in Ittoqqortoormiit and 40 in Tasiilaq (Fig. 1C, Table 5).

Observations of three open-water hunts in Ittoqqortoormiit in August 2015 and 2017 showed an average of 64% of whales shot at in open water hunts were retrieved (21 Aug. 2015: 4 of 5 whales retrieved, 22 Aug. 2015: 1 of 2 whales retrieved, and 26–27 Aug. 2017: 2 of 4 whales retrieved) (GINR[7]). It is, however, unknown if the whales that were not retrieved were mortally wounded. Furthermore, netting of narwhals is allowed in East Greenland, and loss rates in nets are considered minimal. About 54% (n = 8 yr; SD = 13) of the catches of narwhals in Ittoqqortoormiit were taken in nets between 2009 and 2017 (Table 5). Most of the hunting in Ittoqqortoormiit takes place during the open-water season (~90%), so a retrieval factor of 0.64 (or a correction factor of 1.57) should be applied to the 46% of the catches that are not taken in nets in Ittoqqortoormiit. In contrast to Ittoqqortoormiit, kayaks and hand-held harpoons are widely used in Tasiilaq, and the correction factor of 5% that is used for the same type of hunt in Qaanaaq can be applied to the catch statistics from Tasiilaq.

[7]Unpubl. data. GINR, Nuuk, 2018.

Discussion

In this compilation, only the coastal catches by inhabitants of Greenland are included, but historically there was also hunting activity by foreign whalers and by the large numbers of expeditions that passed through Baffin Bay in search of the Northwest Passage or with the goal of reaching the North Pole (Mitchell and Reeves, 1981). Whalers were especially known to have taken narwhals during periods when the bowhead whale hunt was unsuccessful. Since the localities of these takes were generally not reported, it was not attempted to include these catches. This of course renders the compilation of catch statistics during

Table 5.—Reported catches of narwhals in Ittoqqortoormiit and Tasiilaq, East Greenland. For Ittoqqortoormiit, the proportion (%) of the community's total annual narwhal catch that was taken using nets is shown for the years 2009 and 2011–2017. Quotas were implemented in 2011 in East Greenland. Data from 1955–1990 from Dietz et al. (1994), and data from 1993–2017 from "Piniarneq[1]."

	Ittoqqortoormiit		Tasiilaq	
Year	Total catch	Caught in nets (%)	Total catch	Total number of catches
1955	18		6	24
1956	10			10
1957	9		5	14
1958	28		1	29
1959	17		9	26
1960	54		2	56
1961	12		4	16
1962			3	3
1963	8		21	29
1964	8			8
1965				0
1966	2		67	69
1967			20	20
1968			30	30
1969	6		17	23
1970	6		47	53
1971	5		33	38
1972	1		25	26
1973	4		18	22
1974	2		40	42
1975	2		2	4
1976	1		8	9
1977	5		14	19
1978	1		1	2
1979	10		20	30
1980	10		49	59
1981	15		128	143
1982	25		84	109
1983	43		12	55
1984	50			50
1985	28		21	49
1986			63	63
1987			19	19
1988	40		11	51
1989	70		19	89
1990	70		88	158
1991				
1992				
1993	9		16	25
1994	17		20	37
1995	34		35	69
1996	8		39	47
1997	9		42	51
1998	21		26	47
1999	19		99	118
2000	11		28	39
2001	52		70	122
2002	54		55	109
2003	6		87	93
2004	39		96	135
2005	50		68	118
2006	93		29	122
2007	42		40	82
2008	39		76[2]	115
2009	14	75	29	43
2010	16		25	41
2011	30	63	15	45
2012	31	35	17	48
2013	47	55	19	66
2014	61	40	18	79
2015	74	57	20	94
2016	38	50	15	53
2017	60	55	33	93

[1]"Piniarneq" refers to a booklet in which hunters note their catches; since 1993, it has provided catch figures. It also functions as an official hunting license and is reissued once a year upon submission of the completed records from the previous year.
[2]55 narwhals taken in ice entrapment in Sermilik.

the 19th century negatively biased to an unknown extent.

The only period where it seems possible to construct a reliable time series is from 1978 through 2017. The time series for that period is, however, suffering from lack of precise catch statistics, especially for the period from 1984 to 1992 when several communities did not always report their catches. Avanersuaq is particularly problematic since there is seven years without catch reports, but also Sisimiut has long periods with inadequate catch reporting. Since 1992, catch reporting from Avanersuaq has been more consistent but with lower catch estimates than those based on the mattak landings. Some unquantifiable underreporting likely occurred during this period in Avanersuaq.

During the past 25 years (1993–2017) the largest narwhal catches have been taken in Uummannaq (mean: 150, SD: 114) followed by Qaanaaq (mean: 112, SD: 32) (Table 2). In the same period, Disko Bay and Upernavik had mean catches of 100 (SD: 59) and 89 (SD: 36), respectively. Catches in Siorapaluk from the Smith Sound stock were rare before 1990 and has not been included in this compilation until 1993. These catches appear to have increased steadily after 1998, perhaps because of less severe ice conditions in spring and/or access to bigger and faster boat. Catches, however, have declined in recent years.

There has been an overall increase in catches in West Greenland during the 20th century, which is especially pronounced after 1950. The increase peaked around 1990, and during the period after 1993 when the new hunting reporting system "Piniarneq" was installed, a significant decline in overall catches has been observed (ANOVA, $p = 0.0001$, $F = 49.6$, $df = 24$), which was mainly caused by the introduction of quotas in 2004. The decline was significant in Uummannaq ($p<0.0001$, $F = 36.3$), Melville Bay ($p = 0.04$, $F = 4.7$), and Disko Bay ($p<0.0001$, $F = 24.3$) but could not be detected in Inglefield Bredning ($p = 0.529$; $F = 0.41$).

For the period 1993–2017, total catches in East Greenland peaked during 1999–2008 with catches of about 120 narwhals for some of the years. In 2009, catches declined but returned to a steady increase in Ittoqqortoormiit after 2011 with an average catch of 49 whales/yr. Catches in Tasiilaq have remained at a lower level during 2009–2017 with an average catch of 21/yr. Catches in Ittoqqortoormiit need to be corrected for whales that are struck-

but-lost in the part of the hunt where whales are shot from boats but not for the part where whales are taken in nets. Corrections are not included in the numbers shown in Table 5. Losses in Tasiilaq are considered to be minimal due to the general use of kayaks and hand harpoons, but catches could be applied a 5% correction factor.

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Meta-population Modeling of Narwhals, *Monodon monoceros*, in East Canada and West Greenland

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Introduction

Individual narwhals, *Monodon monoceros*, return to the same summer grounds year after year, with a meta-population structure that reflects the geographical distinctiveness of the areas (Heide-Jørgensen et al., 2013). This study identifies eight aggregations, or stocks, of narwhal in the Baffin Bay region of East Canada and West Greenland (JWG, 2015a). We examine the local dynamics of these stocks to assess the cumulated impacts of hunting in the overall area.

We perform our assessment within the Joint Working Group (JWG) of the North Atlantic Marine Mammal Commission (NAMMCO) and the Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga (JCNB). A main challenge is the divergence between the population structure and the geographical and yearly structure of the hunt. Hunts occur not only on summer grounds, but also on spring/fall migration and winter grounds where they target individuals from several summer aggregations (Watt and Hall, 2018; Garde and Heide-Jørgensen, 2019). This led to the development of a catch allocation model that uses satellite tracking, expert judgment, and abundance estimates to allocate the catches from 24 seasonal and geographically separated hunts among the eight summer aggregations of narwhals (JWG, 2015a; Watt et al., 2019).

We use the allocation model to estimate historical catch distributions for each of the eight summer aggregations. Population dynamic models then use these distributions to assess the impacts of the hunt. We integrate the catch allocation and population dynamics models to assess the sustainability of current and future catches, as identified by the cumulated impacts of the 24 hunts on the eight narwhal aggregations.

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Catch Allocation

The geographical locations of the eight summering areas and the different hunting grounds are shown in Watt et al. (2019: Fig. 1 and 2). The catch allocation model (Watt et al., 2019) uses an allocation matrix ($A_{i,j,t}$) to transform

$$c_{i,t} = \sum_{j=1}^{24} A_{i,j,t} H_{j,t} \qquad (1)$$

the catch histories ($H_{j,t}$) of total removals in the 24 hunts (Suppl. Tables S1 and S2) into catch histories ($c_{i,t}$) for the eight summer stocks (i:stock; j:hunt; t:year).

The allocation matrix gives the proportion of the jth hunt that is taken from the ith summer aggregation in year t, and it is estimated

$$A_{i,j,t} = \frac{P_{i,j} N_{i,t}}{\Sigma_i P_{i,j} N_{i,t}} \qquad (2)$$

from the proportional availability ($P_{i,j}$) of the individuals in the different summer aggregations to the different hunts, and the abundance of the different summer aggregations ($N_{i,t}$). This calculation assumes that for each summer aggregation there is a proportion between zero and one, $P_{i,j}$, that is available to hunters during the hunting period on the hunting grounds. All the individuals that are available to a hunt from different stocks are then at equal risk of being taken in the hunt.

Availability Matrix

The cells in the proportional availability matrix (P, Table 1) reflect the

ABSTRACT—Narwhals, Monodon monoceros, *in the Baffin Bay region of East Canada and West Greenland are aggregated into eight summer stocks, and they are hunted in 24 geographically and seasonally separated hunts. Several of the hunts target animals from different stocks, making sustainable management challenging.*

We develop a meta-population model to face the challenge. We use a catch allocation model to allocate the catches in the different hunts into historical time-series distributions for the total removals from each stock. Bayesian population dynamic modeling then analyzes the impacts of the 24 hunts on the eight stocks. The catch allocation, however, depends on the population dynamics. Thus, we integrate the allocation and population modeling in iterative runs until the estimated catch histories and population trajectories converge.

This framework is useful for sustainability assessment and management practices. The allocation model assigns catches to stocks, and the population modeling estimates sustainability for each stock. When done in retrospect it judges the sustainability of current takes. Acting on these measures, managers can use forward projections to identify overall hunting patterns that secure sustainability for all narwhals in the Baffin Bay region.

Table 1.—The proportional availability matrix (P) of narwhals from summer aggregations to hunting regions, as defined by beta(α,β) distributions where $\alpha = x+1$ and $\beta = y-x+1$, with x/y being the availability ratio (x: available; y: total). Numbers 0 and 1 are defined zeros (x/y = 0/9999) or hunts (x/y = 9999/9999), bold numbers are partial hunts, and x/y = 0/n is probable zeros and x/y = n/n probable hunts for sensitivity analysis by changes in n. Summer aggregations: Smith: Smith Sound; Jones: Jones Sound; Inglefield: Inglefield Bredning; Melville: Melville Bay; Somerset: Somerset Island; Admirality: Admirality Inlet; Eclipse: Eclipse Sound; Baffin: East Baffin Island. Hunts: CCA: Canadian Central Arctic; BIC: Central Baffin Island; BIS: South Baffin Island.

Hunt	Season	Smith	Jones	Inglefield	Melville	Somerset	Admiralty	Eclipse	Baffin
Etah	Spring	1	0/*n*	0	0	0	0	0	0
Qaanaaq	Summer	0	0	1	0	0	0	0	0
Grise Fjord	Spring	0/*n*	1	0/*n*	0	0/*n*	0	0	0
Grise Fjord	Summer	0	1	0	0	0	0	0	0
Grise Fjord	Fall	0/*n*	1	0/*n*	0	0/*n*	0	0	0
Upernavik	Summer	0	0	0	1	0	0	0	0
Ummannaaq	Fall	0/*n*	0/*n*	0/*n*	1/9	1	0/42	0/26	0/*n*
Disko Bay	Winter	0/*n*	0/*n*	0/*n*	1/7	0/*n*	1/42	1/6	0/*n*
CCA	Spring	0	0	0	0	1	0/4	0/5	0
CCA	Summer	0	0	0	0	1	0	0	0
CCA	Fall	0	0	0	0	1	7/42	1/26	0
Arctic Bay	Spring	0	0	0	0	1	1	1/5	0
Arctic Bay	Summer	0	0	0	0	0	1	0	0
Arctic Bay	Fall	0	0	0	0	0/*n*	1	6/26	0
Pond Inlet	Spring	0	0/*n*	0/*n*	0	2/2	4/4	1	0/*n*
Pond Inlet	Summer	0	0	0	0	0	0	1	0
Pond Inlet	Fall	0	0/*n*	0/*n*	0	0/14	4/42	1	0/*n*
BIC	Spring	0	0/*n*	0/*n*	0	0/2	0/4	0/6	1
BIC	Summer	0	0	0	0	0	0	0	1
BIC	Fall	0	0/*n*	0/*n*	0	0/5	10/42	16/26	1
BIS	Spring	0	0	0	0	0/2	0/4	0/6	*n*/*n*
BIS	Summer	0	0	0	0	0	0	0	1
BIS	Fall	0	0	0	0	0/5	0/42	2/26	*n*/*n*
BIS	Winter	0	0	0	0	0/2	0/42	1/6	*n*/*n*

migration of narwhals in the overall region, as determined from satellite tracking and expert knowledge. The JWG (2015a) reviewed each cell in the matrix and gave it one of five designations:

Defined zero: Cells with unlikely hunts. Like hypothetical summer hunts that take animals from different areas (narwhals that are harvested by Grise Fjord during summer are from Jones Sound by definition, and they are thus not taken from the Melville Stock), and hunting areas that are not visited by a summer stock given known movements.

Probable zero: Unlikely hunts with no tracking data. The summer aggregation is unlikely hunted, but proximity and/or migration do not rule out potential takes.

Partial hunt: Satellite tracking shows that at least some of the animals in the summer aggregation are available to the hunt.

Probable hunt: Likely hunts with no tracking evidence. The summer aggregation is likely to be fully available to the hunt given geographical proximity and/or migration.

Defined hunt: Hunts on stocks in their summer area or known winter area.

Each cell in P is parameterised as a beta(α,β) distribution, where $\alpha = x + 1$ and $\beta = y - x + 1$ depends on the designation of the hunt: For a partial hunt that is parameterised by the seasonal and geographical distribution of y satellite tracked individuals, x is the number of the individuals that migrated to the hunting ground; Defined zeros are obtained by $x = 0$ and $y = 9999$; Defined hunts by $x = 9999$ and $y = 9999$; Probable zeros by $x = 0$ and $y = n$; and Probable hunts by $x = y = n$. The simulations in this paper set $n = 9999$, which implies that they do not distinguish between probable and defined designations.

Catch Histories

Watt and Hall (2018) and Garde and Heide-Jørgensen (2019) estimated catch histories of total removals for each hunt from reported catches and best knowledge on struck and loss (Table S1 and S2). The transformation of these catches by Eq. (1) into catch histories for each of the eight stocks occurs with a fixed value for each cell in the allocation matrix. Hence, to capture the uncertainty in the allocation—as represented by the uncertainty of the proportional availability matrix and the uncertainty on the abundance of the different summer aggregations—we used simulations with random draws to generate catch history distributions for all summer aggregations.

For a given year, we use an abundance estimate with a coefficient of variation (CV) for all summer aggregations. The distributions of catch histories for the summer aggregations are then generated by a large number of runs of the allocation model over the entire catch history with yearly random draws of each abundance estimate (log-normal based on point estimate and CV) and cell in the proportional availability matrix (with draws from the underlying beta distributions).

To obtain abundance estimates with CV's for all years for all summer aggregations we use subsequent runs of the catch allocation and population dynamic models. For an initial run of the allocation model, the abundance and CV estimates for a given summer aggregation are the linear time transitions between the available survey es-

Table 2.—Absolute and relative [in brackets] abundance estimates (with CV's) for the modeling of the eight summer aggregations of narwhal (from Heide-Jørgensen et al., 2010; Hansen et al.[1]; JWG, 2015a; Higdon and Ferguson, 2017; Doniol-Valcroze et al.[2]). Winter surveys from West Greenland (Heide-Jørgensen and Acquarone, 2002) and the North Water (Heide-Jørgensen et al., 2016) have uncertain stock origin and are not included in the modeling.

Year	Smith	Jones	Inglefield	Melville	Somerset	Admiralty	Eclipse	Baffin
1975	-	-	-	-	-	28260; 0.22	-	-
1981	-	-	-	-	32520; 0.1	-	-	-
1985	-	-	[3164; 0.13]	-	-	16400; 0.43	-	-
1986	-	-	8710; 0.25	-	-	-	-	-
1996	-	-	-	-	45360; 0.35	-	-	-
2001	-	-	[2297; 0.35]	-	-	-	-	-
2002	-	-	[1478; 0.25]	-	35810; 0.43	-	-	-
2003	-	-	-	-	-	5360; 0.5	-	10070; 0.31
2004	-	-	-	-	-	-	20230; 0.36	-
2007	-	-	8370; 0.25	6020; 0.86	-	-	-	-
2009	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	18050; 0.22	-	-
2012	-	-	-	2980; 0.39	-	-	-	-
2013	16360; 0.65	12690; 0.33	-	-	49770; 0.2	35040; 0.42	10490; 0.24	17560; 0.35
2014	-	-	-	3090; 0.5	-	-	-	-

[1]Hansen, R. G., S. Fossette, N. H. Nielsen, M. H. S. Sinding, D. Borchers, and M. P. Heide-Jørgensen. 2015. Abundance of narwhals in Melville Bay in 2012 and 2014. NAMMCO/SC/22-JCNB/SWG/2015-JWG/14.

[2]Doniol-Valcroze, T., J. F. Gosselin, D. Pike, J. Lawson, N. Asselin, K. Hedges, and S. Ferguson. 2015. Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013. DFO. Can. Sci. Advis. Sec. Res. Doc. 2015, 60 p. (Avail. at https://waves-vagues.dfo-mpo.gc.ca/Library/362110.pdf).

timates in Table 2. The abundance in subsequent runs are instead the trajectories that were estimated by the previous run of the population dynamic models, given the catch histories that were estimated by the previous run of the allocation model. This iterative running of the two models occurs until convergence of the catch histories and abundance trajectories.

Population Dynamics

Separate population models with density regulated growth were constructed for each of the eight summer aggregations of narwhals. All the models were based on an age and sex structured Bayesian modeling framework that has been used in earlier applications for walrus, *Odobenus rosmarus* (Witting and Born, 2005, 2014), large cetaceans (Witting, 2013), beluga, *Delphinopterus leucas* (Heide-Jørgensen et al., 2016a,b), and narwhal (e.g., Witting and Heide-Jørgensen[1,2,3]).

Some of the summer aggregations have only been surveyed once, and a full age-structured model is clearly over parameterized for these cases if the main purpose is parameter estimation by maximum likelihood. Yet, our main purpose is to use a Bayesian framework to integrate prior knowledge on the life history biology of narwhals with survey estimates of abundance for the construction of realistic population dynamic models.

Witting[4] used the case of belugas in West Greenland to analyze for influence of model uncertainty in the construction of realistic population models in Bayesian assessments of density regulated growth. Assessments were made for one age-structured and four structurally different discrete models, with all assessments being based on the same data. All models gave very similar estimates of current abundance and current production levels.

We chose an age and sex structured framework that allows the model to be constructed directly from our prior knowledge of the life history of narwhals. This allows also for a later inclusion of sex structured catches and age-structured catch data, as done in other assessments (Hobbs et al., 2015; Witting and Heide-Jørgensen[1,2,3]). Age-structured data, however, were not included here, as we wanted to keep the population dynamic models relatively simple, comparable across summer aggregations, and fast to simulate.

Let $A = 15$ be the maximum lumped age-class of the model. Let the number $N^{m/f}_{a,t+1}$ of males (m) and females (f) in age-classes $0 < a < A$ in year $t + 1$ be

$$N^{m/f}_{a+1,t+1} = p^{m/f}_a N^{m/f}_{a,t} - c^{m/f}_{a,t} \quad (3)$$

and the number of animals in age-class A be

$$N^{m/f}_{A,t+1} = p^{m/f}_A N^{m/f}_{A,t} + p^{m/f}_{A-1} N^{m/f}_{A-1,t} - c^{m/f}_{A,t} - c^{m/f}_{A-1,t} \quad (4)$$

where $p^{m/f}_a$ is the age specific survival rate of males/females, and $c^{m/f}_{a,t}$ is the age specific catch of males/females in year t. The age and gender (g) dependent survival rates $p^g_a = p\tilde{p}^g_a$ are given as a product between a survival scalar p and a relative ($0 < \tilde{p}^g_a \leq 1$) survival rate, with relative survival being one for males and females older than one year of age. The age and gender specific catches $c^{m/f}_{a,t} = c^{m/f}_t \tilde{c}^{m/f}_a$ in year t is given as a product between the total catch of males/females ($c^{m/f}_t$), as specified by the catch history, and an age-specific catch selectivity ($\tilde{c}^{m/f}_t$) that is uniform except that no animals are taken from age-class zero.

The number of females and males in age-class zero is $N^f_{0,t} = \vartheta N_{0,t}$ and $N^m_{0,t} = (1-\vartheta)N_{0,t}$, where ϑ is the fraction of females at birth, and

$$N_{0,t} = \sum_{a=a_m}^{A} B_{a,t} \quad (5)$$

where a_m is the age of the first reproductive event and $B_{a,t}$, the number of births from females in age-class a, is

$$B_{a,t} = b_{a,t}\tilde{b}_a M^f_{a,t} \quad (6)$$

where $b_{a,t}$ is the birth rate in year t for age-class a females should they be at their age-specific reproductive peak, $0 < \tilde{b}_a \leq 1$ is the relative age-specific birth rate (1 for all mature females), and $M^f_{a,t}$ is the number of mature females in age-class a in year t, defined as

$$M^f_{a,t} = \begin{cases} 0 & \text{if } a < a_m \\ N^f_{a,t} & \text{if } a \geq a_m \end{cases} \quad (7)$$

Let $b_{a,t}$ be

[1]Witting, L., and M. P. Heide-Jørgensen. 2012a. Assessment of East Greenland narwhals. NAMMCO/SC/19-JCNB/SWG/2012-JWG/12.

[2]Witting, L., and M. P. Heide-Jørgensen. 2012b. Assessment of West Greenland narwhal (excluding Uummannaq). NAMMCO/SC/19-JCNB/SWG/2012-JWG/10.

[3]Witting, L., and M. P. Heide-Jørgensen. 2012c. Estimation of dynamics for narwhals in Uummannaq, West Greenland. NAMMCO/SC/19-JCNB/SWG/2012-JWG/11.

[4]Witting, L. 2009. Model uncertainty on assessments of West Greenland beluga and narwhals. NAMMCO/SC/16-JCNB/SWG/2009-JWG/12.

$$b_{a,t} = b^* + [b_{\max} - b^*][1 - (\hat{N}_t/\hat{N}^*)\gamma] \quad (8)$$

for density regulated growth where b^* is the birth rate at population dynamic equilibrium (assuming zero catch and equilibrium denoted by $*$), b_{max} is the maximal birth rate, γ is the density dependence parameter, and the abundance component that imposes density dependence is the one-plus component

$$\hat{N}_t = \sum_{a=1}^{A} N^f_{a,t} + N^m_{a,t} \quad (9)$$

Given a stable age-structure and no catch, let λ be a constant defined by $\hat{N}_{t+1} = \lambda \hat{N}_t$. The sustainable yield is then $sy = \hat{N}(\lambda - 1)$, with an optimum $\partial sy/\partial \hat{N} = 0$; the maximum sustainable yield (msy) at $\hat{N}_{msy}$, also known by the maximum sustainable yield rate (msyr = $msy/\hat{N}_{msy}$) and the maximum sustainable yield level (msyl = $\hat{N}_{msy}/\hat{N}^*$).

Statistical Methods

The population dynamic model for each summer aggregation was fitted to the abundance estimates for that stock (Table 2) by subtracting the historical catches from the projection. The eight narwhal stock models provide an interlinked meta-population model by the allocation of catches from the 24 hunts. When catches have been allocated among the different stocks, the fitting of each of the eight population dynamic models occurs independently of the seven other models. The only statistical link between the eight models is the dependence of the catch allocation on the simulated abundance trajectories, and this calculation occurs in-between the independent fits where the population models use the catch histories from the previous run of the allocation model.

One implication of this statistical independence of the eight population dynamic models is that the meta-population model is robust to unbalanced data sets. Should there be more abundance data for one stock compared with others, and/or should age-structured data be included only for some stocks, the likelihood of the data-rich stocks would not dominate an overall likelihood with the risk of biasing the parameter estimates for the data-poor stocks.

The independent estimation of each of the eight population models is done using the same Bayesian statistical method (e.g., Berger, 1985; Press, 1989), where posterior estimates of model parameters and other management related outputs are calculated. This implies an integration of the product between a prior distribution for each parameter and a likelihood function that links the probability of the data to the different parameterizations of the model.

Table 3.—Prior distributions for the different models (*M*). The list of parameters: N_0 is the initial abundance, N^* the population dynamic equilibrium abundance, p the yearly survival, p_0 the first year survival, b the birth rate, a_m the age of the first reproductive event, ϑ the female fraction at birth, γ the density regulation, c_h the catch history, and β the bias of the relative abundance estimate for Inglefield Bredning. Abundance is given in thousands. The prior probability distribution is given by superscripts; *u*: uniform (min,max), *U*: log uniform (min,max), *b*: beta $\left[\begin{smallmatrix} a,b \\ l,x \end{smallmatrix}\right]$ with *i*=min and *x*=max, and *f*: file distribution. No superscript: fixed value.

M	N_0	N^*	p	P_0	b	a_m	ϑ	γ	C_h	β
Smith	-	$2{,}80^U$	2.2^b 0.95,1	$0.5{,}1^u$	0.33	2.2^b 7,15	0.5	$2{,}4^u$	f	-
Jones	-	$2{,}60^U$	2.2^b 0.95,1	$0.5{,}1^u$	0.33	2.2^b 7,15	0.5	$2{,}4^u$	f	-
Inglefield	$1{,}25^U$	$3{,}30^U$	2.2^b 0.95,1	$0.5{,}1^u$	0.33	2.2^b 7,15	0.5	$2{,}4^u$	f	$0.01{,}1^U$
Melville	$0.8{,}20^U$	$3{,}30^U$	2.2^b 0.95,1	$0.5{,}1^u$	0.33	2.2^b 7,15	0.5	$2{,}4^u$	f	-
Somerset	$5{,}60^U$	$25{,}90^U$	2.2^b 0.95,1	$0.5{,}1^u$	0.33	2.2^b 7,15	0.5	$2{,}4^u$	f	-
Admiralty	-	$10{,}40^U$	2.2^b 0.95,1	$0.5{,}1^u$	0.33	2.2^b 7,15	0.5	$2{,}4^u$	f	-
Eclipse	-	$5{,}50^U$	2.2^b 0.95,1	$0.5{,}1^u$	0.33	2.2^b 7,15	0.5	$2{,}4^u$	f	-
Baffin	-	$3{,}60^U$	2.2^b 0.95,1	$0.5{,}1^u$	0.33	2.2^b 7,15	0.5	$2{,}4^u$	f	-

Prior Distributions

Each of the eight population models start in 1970 with the same priors on the biological parameters (see Table 3). Earlier applications for narwhals have used uniform priors for adult survival (p) and the age of first reproduction (a_m). Following discussions at JWG (2018), these were changed to symmetric hump-formed beta distributions ($a = b = 2$) that allocate more weight on the center of the distributions. Given our best knowledge on narwhal life histories (Garde and Heide-Jørgensen[5]), the assumed minimum and maximum values were set to 0.95 and 0.995 for p, and 7 and 15 years for a_m.

As the birth rate (b) and first year survival (p_0) multiply together to determine the number of narwhal at age one, we decided to set the prior on b to a single value, instead of a distribution, in order to reduce the number of parameter estimates. This value was set to 0.33 to reflect the widespread 3-year calving interval in narwhals. As for many other species, there is hardly any knowledge on first year survival in narwhal, except that it is likely to be smaller and more fluctuating than adult survival. We use a uniform prior from 0.5 to 1 for p_0, to capture a first year survival that range from $p/2$ to p.

Admiralty Inlet and all the summer aggregations with only one or two abundance estimates available (Smith Sound, Jones Sound, Eclipse Sound, East Baffin Island) seems to have had a very low exploitation rate in the beginning of the period. For these we assumed that the population was close to carrying capacity in 1970. For the remaining aggregations (Inglefield Bredning, Melville Bay, Somerset Island), with a somewhat larger historical exploitation, we assume that the abundance in 1970 was smaller than carrying capacity. Hence, for each prior draw of the carrying capacity, we continued to draw the 1970 abun-

[5]Garde, E., and M. P. Heide-Jørgensen. 2017. Update on life history parameters of narwhals (*Monodon monoceros*) from East and West Greenland. North Atlantic Marine Mammal Commission/Joint Commission on Narwhal and Beluga Report NAMMCO/SC/24-JCNB/SWG/2017-JWG/16.

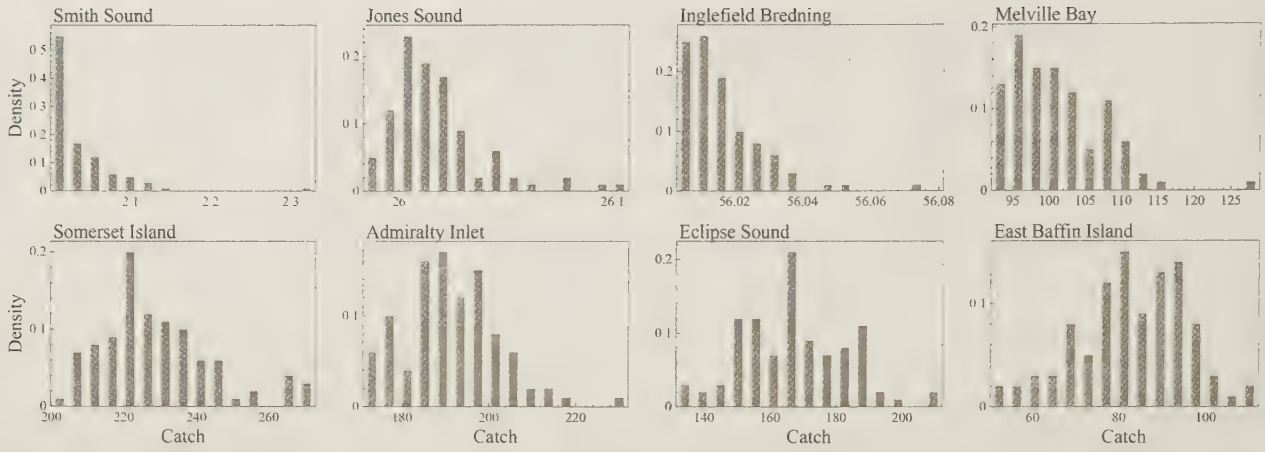

Figure 1.—Catch distributions per summer aggregation, estimates for year 2011.

dance from the prior until the latter was smaller than the former.

The allocation model estimated the catch distributions over the complete catch history starting in 1970. We used these distributions to generate catch priors for the population models, with draws from the prior generating specific catch histories for each iteration of a population model.

The prior distributions of catches for a given year were based on distributions of total removals that were estimated for 2011 by 200 random draws of the allocation model (Fig. 1). The choice of 2011, instead of another year, is rather arbitrary, except that we wanted to use a relatively recent year with high confidence in the reporting of catches. The prior distributions of the catches in time were based on two complete catch histories, a minimum catch history (c_{min}, set to the 1th percentile of the distribution of catches for given years) and a maximum catch history (c_{max}, 99th percentile). The 2011 distribution was then rescaled to run from zero to one, with a value (x) drawn at random from this distribution for each parameterization of a population model, with the catch history for the iteration being calculated as $c_t = c_{min,t} + x(c_{max,t} - c_{min,t})$.

Bayesian Integration

The Bayesian integration was obtained by the sampling-importance-resampling routine (Jeffreys, 1961; Berger, 1985; Rubin, 1988), where n_s random parameterizations θ_i ($1 \le i \le n_s$) are sampled from an importance function $h(\theta)$. This function is a probability distribution function from which a large number, n_s, of independent and identically distributed draws of θ can be taken. $h(\theta)$ shall generally be as close as possible to the posterior, however, the tails of $h(\theta)$ must be no thinner (less dense) than the tails of the posterior (Oh and Berger, 1992). For each drawn parameter set θ_i the population was projected from the first year with a harvest estimate to the present. For each draw an importance weight, or ratio, was calculated

$$w(\theta_i) = \frac{L(\theta_i)\,p(\theta_i)}{h(\theta_i)} \qquad (10)$$

where $L(\theta_i)$ is the likelihood given the data, and $h(\theta_i)$ and $p(\theta_i)$ are the importance and prior functions evaluated at θ_i. In the present study the importance function is set to the joint prior, so that the importance weight is given simply by the likelihood. The n_s parameter sets were then re-sampled n_r times with replacement, with the sampling probability of the ith parameter set being

$$q_i = \frac{w(\theta_i)}{\sum_{j=1}^{n_s} w(\theta_j)} \qquad (11)$$

This generates a random sample of the posterior distribution of size n_r.

The likelihood L was calculated under the assumption that observation errors are log-normally distributed

$$L = \prod_i \prod_t \exp\left(-\frac{[\ln(\hat{N}_{i,t}/\beta_i N_t)]^2}{2cv_{i,t}^2}\right)/CV_{i,t} \qquad (12)$$

where $\hat{N}_{i,t}$ is the point estimate of the ith set of abundance data in year t, $CV_{i,t}$ is the coefficient of variation of the estimate, N_t is the simulated abundance, and β_i a bias term which is set to one for absolute abundance estimates.

Management Objectives

We use the Bayesian framework to estimate the probabilities of meeting an assumed management objective for potential future catches from each of the eight narwhal populations. We usually calculate our advice for the JWG by projecting five years into the future, with an assessment in year t calculating sustainability over the period from t to $t + 5$.

Given future annual catches c in the period t to $t + 5$, we apply the objective

$$\text{ob} = \begin{cases} N_{t+5} > N_t & \text{if } N_t < N^* \text{msyl} \\ c \le 0.9\ \text{msy} & \text{if } N_t \ge N^* \text{msyl} \end{cases} \qquad (13)$$

Given the population dynamic model and the data, the probability of meeting the objective (ob) is straightforwardly calculated from the Bayesian

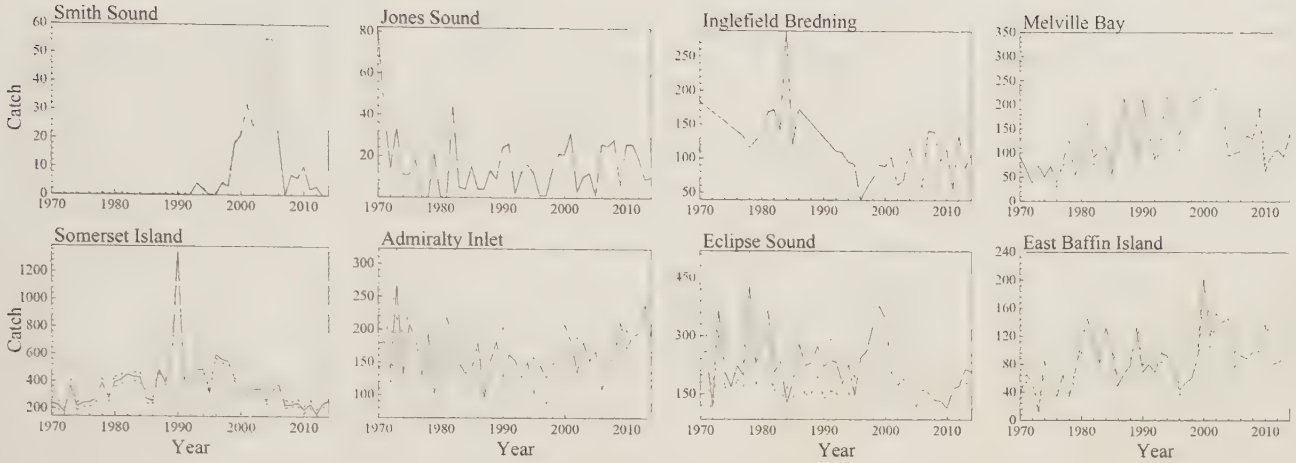

Figure 2.—Yearly catches per summer aggregation with 90% confidence intervals.

statistical method. For each parameterization θ_i of the random sample of the posterior distribution of size n_r, we have perfect knowledge of the status of the population so that it can be determined whether Eq. (13) is true or false. Hence, the probability $p(\text{ob})$ of meeting the objective is

$$p(ob) = \sum_{i=1}^{n_r} g(\theta_i, c)/n_r$$
$$g(\theta_i, c) = \begin{cases} 1 & \text{if ob is true} \\ 0 & \text{if ob is false} \end{cases} \quad (14)$$

with the sum given over the complete random sample of the posterior distribution.

The sustainability of the hunts operates at the population level, but our recommendations on future use relate to hunting grounds. To achieve this, for a given set of potential future catches across hunts, we use the allocation model to calculate the distributions of future catches for the eight populations, with these distributions reflecting the uncertainty in the allocation of catches between populations. We can then calculate the probability of meeting the management objective for each percentile of the catch distribution for each population. This allows for an adjustment of the potential catches in future hunts until the probabilities of fulfilling management objectives exceed agreed thresholds for all populations.

Results and Discussion

The catch distributions and abundance trajectories of the allocation and population dynamic models need relatively few iterative simulations to converge, with stable estimates obtained after four to five iterations (Suppl. Fig. 1).

The estimated catch distributions (Fig. 2) are extremely narrow for Smith Sound, Jones Sound, and Inglefield Bredning. As evident from the proportional availability matrix (Table 1), this reflects a migration and hunting pattern where these animals are taken almost exclusively on their summer grounds. The catch history for Sommerset Island has a slightly wider distribution that reflects animals taken in combinations with animals from other summer grounds during the fall hunt in Ummannaaq and the spring hunt in Pond Inlet. Being harvested in several multi-stock areas during winter and migration, the catch distributions for Melville Bay, Admirality Inlet, and Eclipse Sound are wider.

The sampling statistics of the last run of the Bayesian population models (Suppl. Table S3) indicate no problems with conversion, as evident also from the posterior and realised prior distributions for all parameters across all models (Suppl. Fig. S2–S9). The posterior updating of the population models fall in two groups, as illustrated by the selected distributions for Jones Sound and Inglefield Bredning in Figure 3. The abundance data for most populations except Inglefield Bredning, Somerset Island, and Admirality Inlet are too few to update the priors on the life history and growth rate related parameters. As illustrated by Jones Sound, this implies posterior estimates that resemble the priors for all parameters, except abundance that is strongly updated for all models. For Inglefield Bredning there is also an updating of the life history parameters, which reflects abundance and catch data that indicate a somewhat smaller growth rate than expected by the prior.

The lack of updating shows that most of the posterior estimates in Table 4 should not be regarded as parameter estimates that follow from the abundance and catch data, but more like best estimates for narwhals in general. This raises the question of overparameterised models. Yet, the estimation of parameters is not the purpose of this study. It is instead to project narwhal populations under the constraints of not only the available abundance and catch data, but also our current knowledge on the life history of narwhals. For this to be possible, it is essential to constrain the models by priors to avoid unrealistic scenarios, and we use the best estimated life history parameters to impose these bounds.

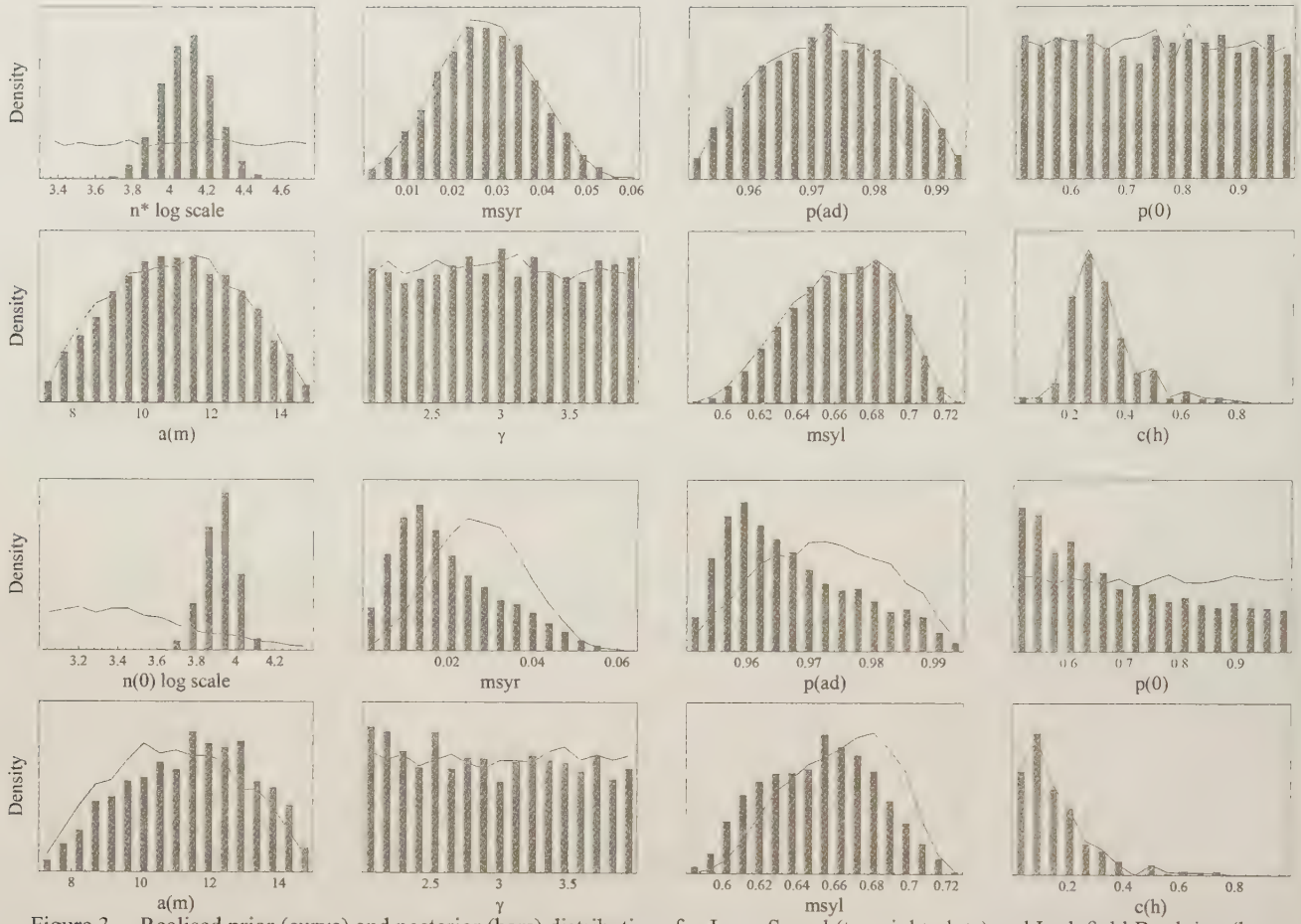

Figure 3.—Realised prior (curve) and posterior (bars) distributions for Jones Sound (top eight plots) and Inglefield Bredning (bottom plots).

Table 4.—Parameter estimates for the different models (*M*). Estimates are given by the median ($x_{0.5}$) and the 90% confidence interval ($x_{0.05}$ - $x_{0.95}$) of the posterior distributions. Abundance is given in thousands. $d = N_{2016}/N^*$.

M		N_0	N^*	r	msyr	p	p_0	a_m	γ	msyl	c_h	d
Smith	$x_{0.5}$	-	16	0.035	0.028	0.97	0.75	11	3	0.67	0.05	1.0
	$x_{0.05}$	-	5.5	0.013	0.01	0.96	0.53	8.1	2.1	0.62	0.006	0.98
	$x_{0.95}$	-	45	0.058	0.045	0.99	0.97	14	3.9	0.7	0.29	1.0
Jones	$x_{0.5}$	-	12	0.035	0.027	0.97	0.75	11	3	0.67	0.29	0.99
	$x_{0.05}$	-	7.2	0.013	0.0097	0.96	0.52	8.1	2.1	0.62	0.17	0.97
	$x_{0.95}$	-	21	0.058	0.046	0.99	0.97	14	3.9	0.7	0.6	1.0
Inglefield	$x_{0.5}$	8.3	11	0.023	0.018	0.97	0.66	12	2.9	0.65	0.12	0.70
	$x_{0.05}$	5.9	7.9	0.006	0.004	0.95	0.51	8.3	2.1	0.6	0.033	0.25
	$x_{0.95}$	11	25	0.056	0.044	0.99	0.95	14	3.9	0.7	0.48	0.95
Melville	$x_{0.5}$	3.8	7.6	0.037	0.029	0.97	0.77	11	3	0.67	0.16	0.39
	$x_{0.05}$	2	4.4	0.015	0.012	0.96	0.53	8	2.1	0.62	0.026	0.11
	$x_{0.95}$	6.8	25	0.06	0.047	0.99	0.98	14	3.9	0.71	0.49	0.78
Somerset	$x_{0.5}$	23	51	0.038	0.029	0.97	0.77	11	3	0.67	0.36	0.92
	$x_{0.05}$	17	36	0.022	0.017	0.96	0.54	8	2.1	0.62	0.075	0.59
	$x_{0.95}$	32	83	0.058	0.045	0.99	0.98	14	3.9	0.71	0.82	0.98
Admiralty	$x_{0.5}$	-	21	0.035	0.027	0.97	0.74	11	3	0.66	0.37	0.92
	$x_{0.05}$	-	17	0.012	0.009	0.96	0.52	8	2.1	0.61	0.086	0.80
	$x_{0.95}$	-	26	0.057	0.045	0.99	0.97	14	3.9	0.7	0.7	0.96
Eclipse	$x_{0.5}$	-	15	0.036	0.028	0.97	0.76	11	3	0.67	0.38	0.87
	$x_{0.05}$	-	11	0.013	0.01	0.96	0.53	8	2.1	0.62	0.077	0.63
	$x_{0.95}$	-	20	0.06	0.046	0.99	0.98	14	3.9	0.71	0.75	0.96
Baffin	$x_{0.5}$	-	13	0.036	0.028	0.97	0.76	11	3	0.67	0.52	0.94
	$x_{0.05}$	-	9.2	0.015	0.011	0.96	0.53	8	2.1	0.62	0.2	0.83
	$x_{0.95}$	-	19	0.058	0.045	0.99	0.98	14	3.9	0.7	0.77	0.98

The estimated population trajectories and underlying abundance data illustrate the general absence of evidence for trends in the available data, with the only exception being perhaps Somerset Island (Fig. 4). We note that the relative data-rich trajectory for Inglefield Bredning is flat, despite the somewhat lower growth rate estimate relative to the other summer aggregations.

Having realistic models for the eight stocks given the data, we estimate future sustainability by projecting five years into the future. From the last assessment of the JWG (2015b), we show the estimated trade-off between the future catch and the probability of fulfilling the management objective for all stocks in Supplementary Table S4. The size of the sustainable

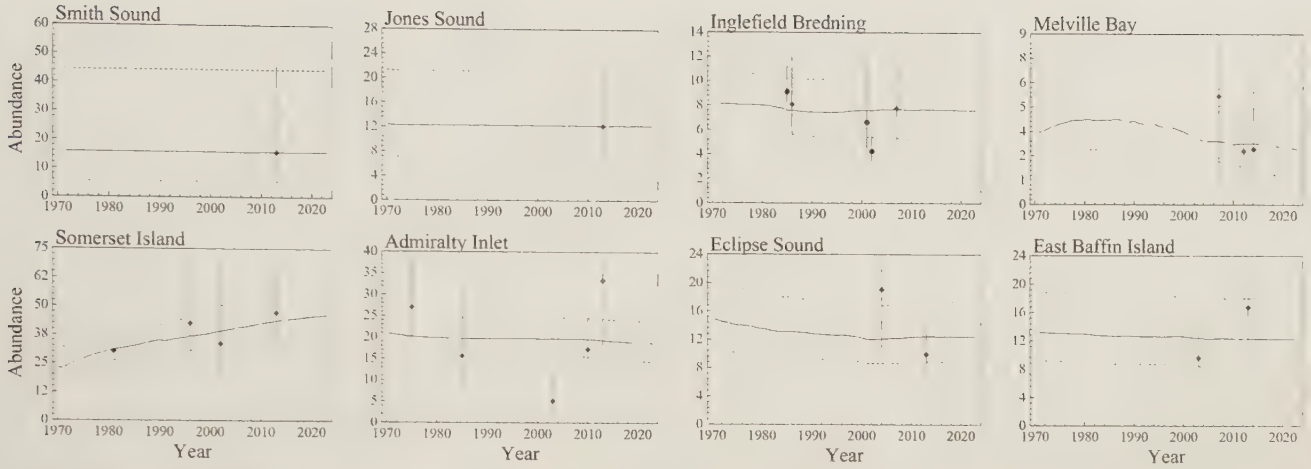

Figure 4.—Trajectories of the different narwhal aggregations. Points with bars are the abundance estimates with 90% confidence intervals. Solid curves are the median, and dotted curves mark the 90% confidence interval, of the estimated models. Abundance is given in thousands.

Table 5.—Examples (C#) of future annual removals per hunting region.

Hunt	Season	C0	C1
Etah	Spring	4	5
Qaanaaq	Summer	98	98
Grise Fjord	Spring	7	9
Grise Fjord	Summer	11	15
Grise Fjord	Fall	0	0
Upernavik	Summer	100	70
Ummannaaq	Fall	86	154
Disko Bay	Winter	73	97
CCA	Spring	4	6
CCA	Summer	74	118
CCA	Fall	2	3
Arctic Bay	Spring	31	41
Arctic Bay	Summer	141	188
Arctic Bay	Fall	0	0
Pond Inlet	Spring	58	77
Pond Inlet	Summer	55	73
Pond Inlet	Fall	4	5
BIC	Spring	12	11
BIC	Summer	100	91
BIC	Fall	44	40
BIS	Spring	5	5
BIS	Summer	9	8
BIS	Fall	12	11
BIS	Winter	0	0

Table 6.—Examples of future annual removals (C#) per summer aggregation, with associated probabilities (P#) of fulfilling management objectives for the eight stocks. The different removals follow from the catch options in Table 5, and the 90% confidence intervals of the estimates are given by sub- and superscripts.

Item	Smith	Jones	Inglefield	Melville	Somerset	Admiralty	Eclipse	Baffin
C0	4^{4}_{4}	18^{18}_{18}	98^{98}_{98}	109^{141}_{141}	219^{265}_{175}	185^{226}_{161}	155^{207}_{104}	134^{152}_{120}
P0	$1.00^{1.00}_{1.00}$	$1.00^{1.00}_{1.00}$	$0.70^{0.70}_{0.70}$	$0.49^{0.56}_{0.26}$	$0.99^{0.99}_{0.99}$	$0.89^{0.92}_{0.83}$	$0.95^{0.98}_{0.89}$	$0.76^{0.81}_{0.68}$
C1	5^{5}_{5}	24^{24}_{24}	98^{98}_{98}	83^{126}_{72}	343^{399}_{283}	243^{296}_{212}	198^{262}_{134}	122^{138}_{110}
P1	$1.00^{1.00}_{1.00}$	$1.00^{1.00}_{1.00}$	$0.70^{0.70}_{0.70}$	$0.70^{0.75}_{0.36}$	$0.97^{0.98}_{0.95}$	$0.80^{0.85}_{0.71}$	$0.90^{0.96}_{0.80}$	$0.80^{0.85}_{0.74}$

catch reflects the size of the stocks. With a 2014 estimate of 3,090 (cv:0.5) animals, Melville Bay is the smallest summer aggregation and no more than 63 individuals should be taken annually from this stock if we want the objective secured with 80% probability. With a 2013 estimate of 49,770 (CV:0.2) narwhals, the largest aggregation occurs around Sommerset Island, and this stock may take an annual removal around 635 individuals given sustainability with 80% probability.

It is, however, impossible to impose regulating quotas directly on narwhal stocks because the hunt occurs not only on summer grounds but also in mixed winter, spring and fall areas. Regulation may instead occur on the different hunts, with Table 5 showing two potential takes that were considered at JWG (2015b). The first (C0) is the average take over the 5-year period from 2009 to 2013, and the second (C1) a more sustainable alternative. These takes are calculated into sustainability measures for the eight stocks in Table 6. It gives the probability of meeting the management objective for the eight stocks, given annual takes of C0 or C1. These probabilities have 90% confidence intervals (CI) that reflect the uncertainty on the origin of the animals that are taken in the different hunts.

Our chances of fulfilling the objective is high for most stocks if the catches from 2009 to 2013 (C0) are continued until 2020. The chances, however, would be no more than 49% (90% CI:26%–56%) for Melville Bay and 76% (90% CI:68%–81%) for East Baffin Island. The C1 option takes 195 narwhals more per year than the C0 option, yet, at the median level, the C1 option ensures a 70% chance of meeting the objective for the two stocks that summer in Greenland (Inglefield Bredning and Melville Bay), and at least a 80% chance for the remaining stocks in Canada. A redistribution of the catches may thus allow for a higher harvest that ensures also a higher minimum level of sustainability across all stocks.

This example illustrates how the meta-population modeling of narwhals in East Canada and West Greenland is a useful tool for sustainability assessment and management practice. The catch allocation model solves the problem of assigning catches to stocks, and the population dynamic modeling takes these catch distributions and calculates sustainability for each of the

eight narwhal stocks. When done retrospectively it judges the sustainability of current takes. Acting on these measures, managers may change the current takes on the 24 hunting grounds and identify hunting patterns that are sustainable for all narwhals in the Baffin Bay region.

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Hunt Allocation Modeling for Migrating Animals: The Case of Baffin Bay Narwhal, *Monodon monoceros*

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Introduction

Marine mammal populations or stocks often have large spatial distributions and follow seasonal migration patterns that expose them to taking by hunters or other risks at different times and locations throughout the year (Heide-Jørgensen et al., 2003; Valenzuela et al., 2009; Foote et al., 2010; Horton et al., 2017), and often across many international jurisdictions (Harrison et al., 2018). Migration patterns follow predictable routes and seasonal timing such that the exposure to potential interactions with anthropogenic activities may occur at a number of locations annually each for a short period of time (Rosenbaum et al., 2013; O'Corry-Crowe et al., 2016; Forney et al., 2017; Watt et al., 2017). Understanding migration of animals and residency time becomes particularly important for sustainable management of hunted species (Harrison et al., 2018). Movement of animals has been considered particularly important for developing and implementing conservation measures (Cooke, 2008; McGowan et al., 2017), but there are few examples where movement and harvest data have been integrated for sustainable management of hunted species (although see Nichols et al., 1995).

Sustainable management of hunting typically divides species into management units, or stocks (hereafter referred to as stocks) that are thought to be self-sustaining, and often defined based on genetic indicators, residency time, site-fidelity, or other life history characteristics (Begg et al., 1999; Hobbs et al., 2019). Movement of animals among hunting regions and hunting regions in which hunters have access to more than one stock pose a particular challenge for ensuring individual stocks are managed sustainably (Allen and Singh, 2016); thus, a modeling approach that accounts for this movement and mixing of stocks is needed (Ogburn et al., 2017). In this way, removals can be attributed to the stock of origin, regardless of the time of year or location of the hunt.

In many cases, genetic samples and phenology of catches are used to estimate the portion of each stock available to hunters at different hunting sites, across seasons (de March and Postma, 2003; Shafer et al., 2014; Doniol-Valcroze et al.[1]). However, in cases such as narwhals, *Monodon monoceros*, where genetic variation is very low (Palsbøll et al., 1997; Westbury et al., 2019; Louis et al., 2020; Petersen et al.[2]) other methods such as telemetry, diet, behavioral studies, or local knowledge may be used to as-

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[1]Doniol-Valcroze, T., J.-F. Gosselin, and M. O. Hammill. 2012. Population modeling and harvest advice under the precautionary approach for eastern Hudson Bay beluga (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/168:iii + 31 p. (http://waves-vagues.dfo-mpo.gc.ca/).

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ABSTRACT— Hunted animals are often managed as static management units, or stocks, specific to hunting regions. However, movement of animals between regions poses a particular challenge for management to ensure that the hunt of individual stocks is sustainable. The incorporation of genetic information in stock assessments can improve management decisions, but the resolution of genetics may not differentiate stocks, making the use of movement data necessary. The Joint Working Group of the North Atlantic Marine Mammal Commission (NAMMCO) and the Canada-Greenland Joint Commission on Conservation and Management of Narwhal and Beluga (JCNB) has developed a model that allocates catches in different hunting regions and seasons to different stocks based on movement data, local knowledge, and expert opinion. The model uses information on stock size, catches in different hunting areas/seasons, and a matrix which estimates the proportion of animals in each stock that are available to hunters in different regions and seasons. This matrix can be informed by quantitative data on stock structure (e.g., genetics, telemetry) or qualitative information (local knowledge, expert opinion, etc.). Uncertainty in the availability of animals and individual stock sizes is incorporated in a stochastic version. The model is presented using a case study of narwhals, which are managed as stocks based on their summer distribution in Canada and Greenland.

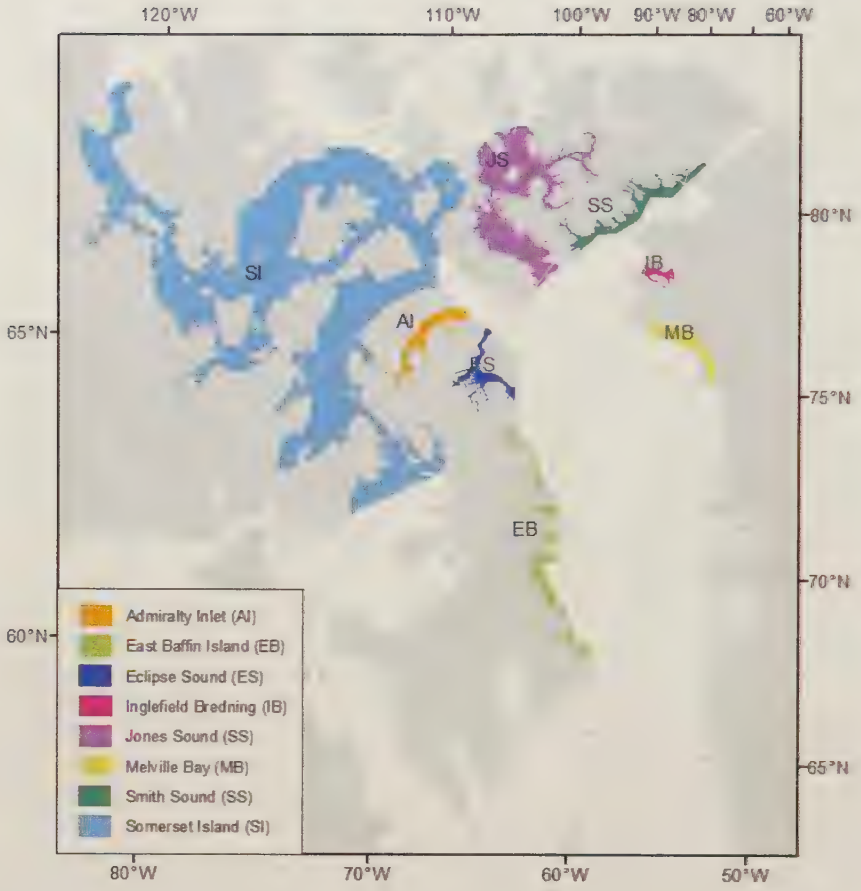


Figure 1.—Summer distribution of narwhal stocks in the Canadian high Arctic and in West Greenland. NSIDC_Sea_Ice_Polar_Stereographic_North projection is used.

sign removals to the stock of origin. In either case, when all takes cannot be assigned positively to a single stock there will be uncertainty in the assignments and a need for a probabilistic assignment scheme.

The Joint Working Group consisting of the North Atlantic Marine Mammal Commission (NAMMCO) Scientific Committee Working Group on the Population Status of Narwhal and Beluga in the North Atlantic and the Canada-Greenland Joint Commission on Conservation and Management of Narwhal and Beluga (JCNB) Scientific Working Group developed a model that estimates the number of animals removed from each stock, using information on movements of each stock to determine which stocks are available to hunters in different hunting areas and seasons. The model has broad application to estimating removals in other migrating marine or terrestrial species impacted by anthropogenic activities (e.g., hunting, exposure to noise, fishery bycatch) in multiple locations and seasons where mixed stocks are present. We developed the model and used it in a case study focused on narwhals.

Narwhals from the Baffin Bay population are part of the subsistence hunt by a number of communities in the Arctic in Canada and Greenland. This population of narwhals is estimated at approximately 140,000 individuals (Doniol-Valcroze et al.[1]), and spends summers in the inlets and fjords of northeastern Canada and western Greenland (Dietz et al., 2001; Heide-Jørgensen et al., 2002, 2003; Laidre et al., 2004; Dietz et al., 2008). Narwhals show site fidelity to their summering region (Heide-Jørgensen et al., 2002, 2003), with nearly all of the few animals tracked by satellite telemetry for a year, returning to the summering aggregation where they were captured (but see Watt et al.[3]). To avoid local depletion, management of the hunt has been based on these individual summer aggregations of the Baffin Bay population, referred to as stocks (Hobbs et al., 2019).

There are six defined narwhal stocks in the Baffin Bay population in northern Canada: the Admiralty Inlet, Somerset Island, Eclipse Sound, East Baffin Island, Smith Sound, and Jones Sound stocks (Doniol-Valcroze et al.[4]) (Fig. 1). In West Greenland there are two defined stocks from the Baffin Bay population: the Melville Bay and Inglefield Bredning stocks (Heide-Jørgensen et al., 2013) (Fig. 1).

Narwhals are hunted in a number of regions across the Canadian Arctic and West Greenland (based on local knowledge; Fig. 2). In Canada, the hunt occurs primarily during summer, but individuals hunted from the Baffin Bay population spend the winter in Davis Strait and Baffin Bay and pass through a number of hunting areas on the migration to and from their summering area (Heide-Jørgensen et al., 2013). In addition, whales from some of the Canadian stocks are also available to hunters in West Greenland on the fall and winter hunting grounds (Heide-Jørgensen et al., 2013).

Narwhal stocks have been managed independently of one another, but because of the mixing of stocks during the migration and on the fall and win-

[3]Watt, C. A., J. Orr, B. LeBlanc, P. Richard, and S. H. Ferguson. 2012. Satellite tracking of narwhals (*Monodon monoceros*) from Admiralty Inlet (2009) and Eclipse Sound (2010-2011). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/046. iii + 17 p. (https://waves-vagues.dfo-mpo.gc.ca/Library/347206.pdf).

[4]Doniol-Valcroze, T., J.-F. Gosselin, D. Pike, J. Lawson, N. Asselin, K. Hedges, and S. Ferguson. 2015. Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/060:v + 36 p. (http://waves-vagues.dfo-mpo.gc.ca/Library/362110.pdf).

ter grounds, a framework that considers stocks to be shared across multiple communities of the two countries was developed to ensure conservation and sustainable management. We present a hunt allocation model that has been applied to narwhal stocks to demonstrate the utility of the model and its ability to inform conservation and management goals for this marine mammal.

Model Development

The stock allocation model assumes that in a region with a hunt from a mixture of stocks, the number of animals taken is proportional to the relative number of individuals from each stock that visit the areas. However, it is often the case that not every animal from a given stock visits the hunting region; i.e., not all individuals from a stock are "available" for the hunt. Probabilities of being taken in the hunt will thus be relative to the portions of each stock that visit the area (instead of their total abundance). Therefore, to allocate removals to the specific stocks, the model requires information on the size of each stock, removals (landed catch plus struck-but-lost) in each hunting region, and the portion of each stock available to hunters in the different locations and seasons. Hunting communities report "landed catch," the number of successfully landed hunted animals; a "struck-but-lost" rate which accounts for animals that were likely killed or severely injured but not recovered and in some cases an "under reporting" rate are applied to the landed catch to estimate total removals (Garde et al., 2019).

Allocation Matrix

The allocation matrix, A, which assigns takes from hunting locations and seasons, is developed in the form of a table with one column for each stock, and rows representing the different areas by season where hunts take place. It is devised so that when transposed and multiplied by a vector of removals by each hunt (area and season) in a year, the number of removals from each stock can be estimated.

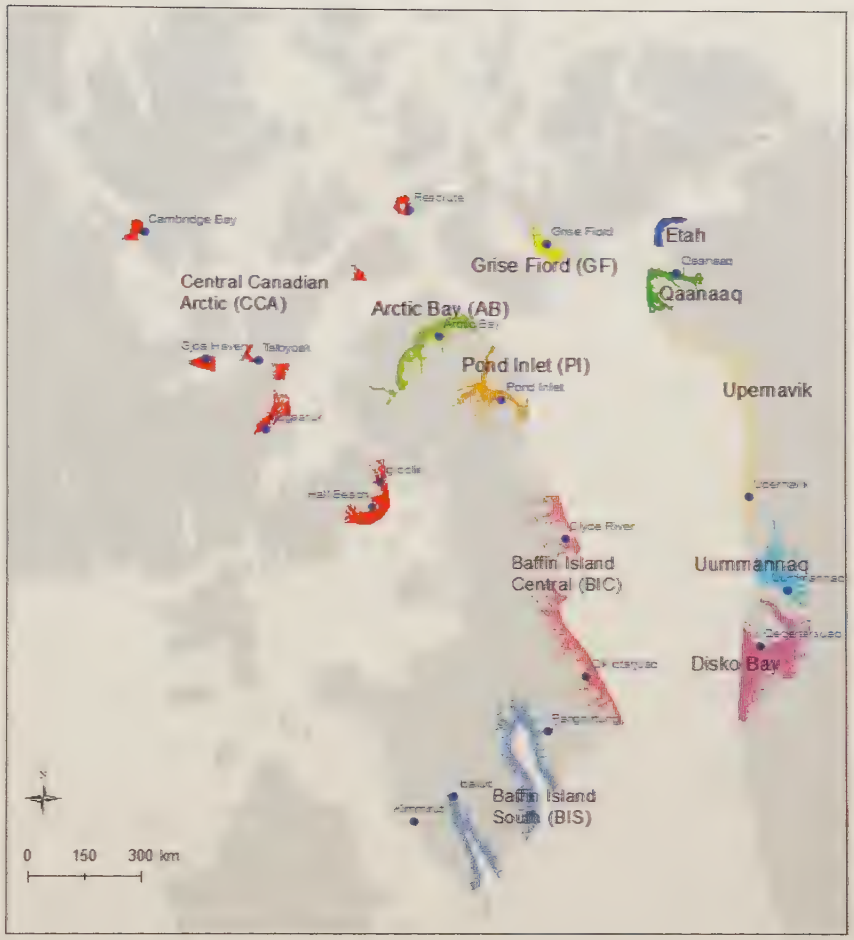


Figure 2.—Harvest locations for narwhal in Canada and Greenland.

Each cell of the allocation matrix, A, has the value:

$$A_{ij} = \frac{P_{ij}N_i}{\Sigma_i P_{ij}N_i}$$

Where,

A_{ij} is the proportion of the jth hunt that is assigned to the ith stock,

P_{ij} is the proportional availability of the ith stock to the jth hunt, an element of the proportional availability matrix, and

N_i is the abundance of the ith stock.

This model assumes that for each stock there is a portion of animals in the stock, between zero and one (P_{ij}), that are available to hunters during the hunting period, on the hunting grounds. Each individual that is available is then at equal risk of being taken in the hunt. The sum of the A_{ij} should be 1 for each row of the matrix so that all animals taken in the hunt are assigned to stocks since each animal originated from one of the stocks. Note that in areas with hunts from mixed stocks, animals will be split among the stocks because of the uncertainty in the stock of origin. The sum of the P_{ij}, however, does not necessarily add up to 1 in each row because it is the fraction of each stock available to hunters, for instance if half of each of three stocks are available at a location then the sum would be 3/2. Likewise the P_{ij}, does not necessarily add up to 1 in each column because the same stocks can be hunted in several regions over the year and across their migration.

Table 1.— Definitions for the five designations given to each cell in the proportional availability matrix.

Number in text	Designation	Definition
1	Defined zero	Impossible situations such as a summer hunt in a location that was not at a summering ground of the stock, or hunts in areas in other seasons that could not have originated in a particular summering ground based on known movements, e.g., the location was not adjacent to the known migration route wintering ground of the stock.
2	Probable zero	Unlikely to be hunted but proximity during the hunting season could not rule out takes completely.
3	Partial hunt	Data shows a portion of the stock is available to hunters.
4	Probable hunt	Proximity between the stock location and hunting region makes movement or migration to the hunting region almost certain, but where no data exists yet to confirm that the stock is available at the location.
5	Defined hunt	Hunts of the stock within their known home range or summer distribution.

Proportional Availability

To set up the proportional availability matrix, P, each cell in the matrix, i.e., hunt of a given stock at a location in a season, is given one of five designations (Table 1), using information from satellite tracking data, geography, seasonal timing, and expert opinion or local knowledge. Expert opinion is defined as opinion from those members of the Joint Working Group that have spent a significant proportion of their career studying these animals. The designation determines how the cell is calculated. Designations "1. Defined zero" and "2. Probable zero" indicate that a stock is very likely or certainly unavailable to the hunt. For "3. Partial hunt", data on structure within the stock suggests that only a portion of the stock is available to a hunt. An example is where data indicate that some animals in a stock travel near shore and others travel far offshore beyond the reach of hunters.

In this example the data (telemetry or other information), and hunter's knowledge and expert opinion on the area hunted are used to determine the proportional availability of the stock at a hunting site by season. The proportion is calculated as the number of animals from a stock that visit a hunting site during the hunting season (x) divided by the total number of animals from that stock for which there is data (n).

Hunting grounds that are known to have only one stock available in a specific season, such as in the summering ground of the stock, are given a designation of "5. Defined hunt", and the proportional availability will be 1 for that hunt, with no uncertainty. However, in cases where it is likely that only one stock is available but the information on animal availability is insufficient, then these hunts are designated as "4. Probable hunt." The distinction between the defined and probable zeros and hunts becomes important in the development of the stochastic allocation matrix described below.

We developed a deterministic version of the model but since there is general uncertainty around the proportional availability in the Partial hunts and some uncertainty also in the Probable zeros and Probable hunts, we also developed a stochastic version of the proportional availability matrix to account for this uncertainty. The deterministic and stochastic matrices P differ in their treatment of the "probable" values, resulting in different versions of the allocation matrix A. In the deterministic or "fixed" version of P, cells with defined (designations 1 and 5 in Table 1) and probable (designations 2 and 4 in Table 1) zeros and hunts are given the value zero or one respectively, and for "3. Partial hunt" the values are calculated from the proportion of animals available in the hunting areas from the tracking data (x/n; as explained above).

In the stochastic version, the defined zeros and hunts are given the values zero and one, respectively, as above, while the proportions for partial hunts (designation 3) as well as probable zeros and hunts (designations 2 and 4) are drawn randomly from beta distributions, with the variance (uncertainty) of the beta distribution increasing with fewer animals with data available or smaller values of the Z parameter (described below). The fixed matrix can be used to provide single value results. The stochastic matrix can be used for sensitivity analysis and risk assessment on its own or with a stochastic vector of abundance estimates or hunt takes.

Quantifying Uncertainty

There are two main sources of uncertainty in the analysis: uncertainty in the proportion of animals from one stock that are available to hunters at a given hunting site (P_{ij}), and errors in stock abundance estimates (N_{it}).

Animal Availability

Uncertainty around the proportion of animals available (P_{ij}) is quantified by assuming that the number of animals observed in a certain area follows a binomial distribution with a sample size equal to the number of animals for which there exists data on availability (n) and a probability equal to the true proportion of the animals in that stock that visit the area. This true proportion is unknown but we assume that the likelihood of any one value follows a beta distribution Beta(x+1, n-x+1) (Johnson and Kotz, 1970) where x is the number of animals that visited the area.

The mean of this distribution is (x+1)/(n+2), which converges towards the mean proportion in the fixed version (x/n) with increasing values of x and n. When no connection is documented between a stock and a hunting ground, we distinguish between connections that are deemed extremely unlikely based on expert opinion and connections that are considered unlikely, but not impossible. The former ("1. Defined zeros" Table 1) are assigned a proportional availability of 0, with no uncertainty. The latter ("2. Probable zeros" Table 1) are also assigned a proportional availability of 0, but are given a Beta(1, Z) probability distribution, where Z is an uncertainty parameter that can vary from 1 to infinity so that the mean of this distribution is 1/(Z+1) (larger values represent

higher certainty i.e., closer to zero). Finally, there is the case of "4. Probable hunt", which is parameterized by a Beta(Z, 1) distribution with mean (Z/Z+1), and represents cases where there are no documented movements, but a strong connection is expected (may be from expert opinion, local knowledge, etc.).

In practice, the parameter Z can be thought of as a hypothetical number of animals for which there is data that would result in no animals visiting a hunting area (i.e., 0/Z number of animals), thus a minimum value for Z would be the number of animals with data to date and higher values would reflect certainty resulting from other sources (such as expert opinion, local knowledge, other data such as unique stable isotope or trace element ratios, etc.). This parameter was used for sensitivity testing of the model, setting Z to be identical for all cells designated as "2. Probable zero" and "4. Probable hunt" assuming Z = 10,000 as the base case (i.e., no uncertainty) which approximates the fixed matrix, to assuming Z as low as the *n* values for each stock.

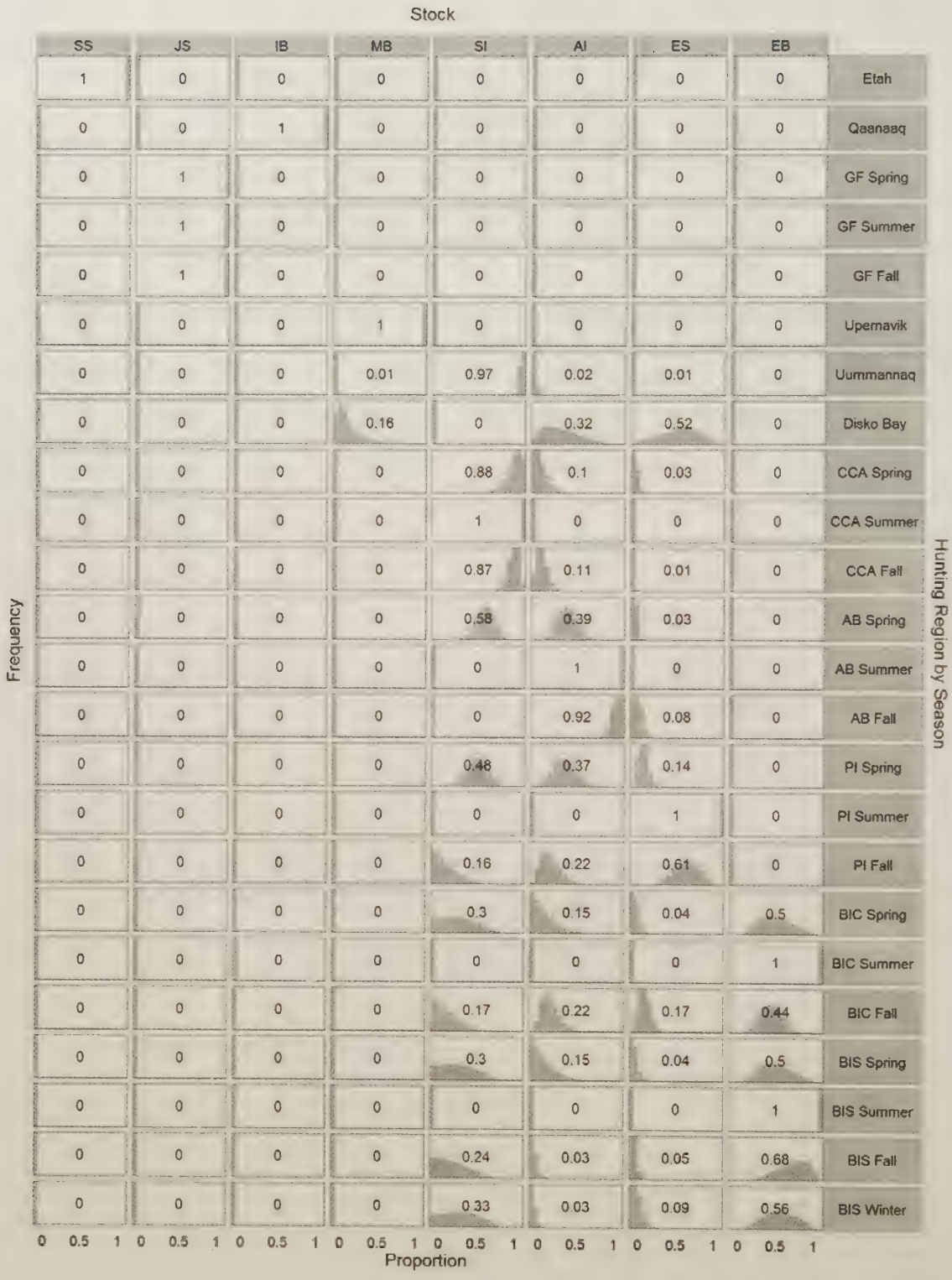
Inclusion of uncertainty changes P_{ij} from a table with fixed values to a table in which each cell is a random variable (see Tables 2 and 3 for example), and therefore changes the resulting allocation matrix A_{ij} from having fixed values to one where each cell contains a probability distribution (see Fig. 3 and 4 for example). For cells with "1. Defined zero" or "5. Defined hunt", these distributions have essentially zero variance and result in a single value of 0 or 1, respectively. Cells with "2. Probable zero" or "4. Probable hunt" have a distribution with mean equal to the corresponding value in the fixed version of the table, for which variance reflects uncertainty around this value. For these probable cells both mean and variance depend on the value of Z. The maximum value of Z=10,000 results in a distribution nearly identical to "1. Defined zero" or

Table 2.—Fixed availability matrix P_{ij} for narwhals from different summering stocks to different hunting regions (*x*/*n*; available (x) / total (*n*)) based on telemetry data (CCA: Central Canadian Arctic, BIC: Baffin Island Central, BIS: Baffin Island South; see Fig. 2 for hunt locations). "1. Defined zero", and "5. Defined hunt" are represented by 0 and 1, respectively, while 0* and 1* indicates "2. Probable zero, and "4. Probable hunt". Ratios reflect information from satellite telemetry data.

Hunt	Season	Smith Sound	Jones Sound	Inglefield Bredning	Melville Bay	Somerset Island	Admiralty Inlet	Eclipse Sound	East Baffin Island
Etah	Spring	1	0*	0	0	0	0	0	0
Qaanaaq	Summer	0	0	1	0	0	0	0	0
Grise Fiord	Spring	0*	1	0*	0	0*	0	0	0
Grise Fiord	Summer	0	1	0	0	0	0	0	0
Grise Fiord	Fall	0*	1	0*	0	0*	0	0	0
Upernavik	Summer	0	0	0	1	0	0	0	0
Uummannaq	Fall	0*	0*	0*	1/9	1	0/42	0/26	0*
Disko Bay	Winter	0*	0*	0*	1/7	0*	1/42	1/6	0*
CCA	Spring	0	0	0	0	1	0/4	0/5	0
CCA	Summer	0	0	0	0	1	0	0	0
CCA	Fall	0	0	0	0	1	7/42	1/26	0
Arctic Bay	Spring	0	0	0	0	1	1	1/5	0
Arctic Bay	Summer	0	0	0	0	0	1	0	0
Arctic Bay	Fall	0	0	0	0	0*	1	6/26	0
Pond Inlet	Spring	0	0*	0*	0	2/2	4/4	1	0*
Pond Inlet	Summer	0	0	0	0	0	0	1	0
Pond Inlet	Fall	0	0*	0*	0	0/14	4/42	1	0*
BIC	Spring	0	0*	0*	0	0/2	0/4	0/6	1
BIC	Summer	0	0	0	0	0	0	0	1
BIC	Fall	0	0*	0*	0	0/5	10/42	16/26	1
BIS	Spring	0	0	0	0	0/2	0/4	0/6	1*
BIS	Summer	0	0	0	0	0	0	0	1
BIS	Fall	0	0	0	0	0/5	0/42	2/26	1*
BIS	Winter	0	0	0	0	0/2	0/42	1/6	1*

Table 3.—Allocation matrix A_{ij} (with no uncertainty) for narwhals from different summering stocks for different hunting regions (CCA: Central Canadian Arctic, BIC: Baffin Island Central, BIS: Baffin Island South; see Figure 2 for hunt locations) and catches for each region. Note that proportions in each line (each site) sum to 1 (all caught animals have to be allocated to a stock). Catches are multiplied by the corresponding allocation proportions for each site, then summed for each stock to yield total removals.

Hunt	Season	Smith Sound	Jones Sound	Inglefield Bredning	Melville Bay	Somerset Island	Admiralty Inlet	Eclipse Sound	East Baffin Island	Catches
Etah	Spring	1	0	0	0	0	0	0	0	0
Qaanaaq	Summer	0	0	1	0	0	0	0	0	87
Grise Fiord	Spring	0	1	0	0	0	0	0	0	5
Grise Fiord	Summer	0	1	0	0	0	0	0	0	0
Grise Fiord	Fall	0	1	0	0	0	0	0	0	4
Upernavik	Summer	0	0	0	1	0	0	0	0	82
Uummannaq	Fall	0	0	0	0.01	0.99	0	0	0	101
Disko Bay	Winter	0	0	0	0.15	0	0.28	0.58	0	66
CCA	Spring	0	0	0	0	1	0	0	0	1
CCA	Summer	0	0	0	0	1	0	0	0	33
CCA	Fall	0	0	0	0	0.89	0.1	0.01	0	23
Arctic Bay	Spring	0	0	0	0	0.57	0.4	0.02	0	43
Arctic Bay	Summer	0	0	0	0	0	1	0	0	167
Arctic Bay	Fall	0	0	0	0	0	0.94	0.06	0	4
Pond Inlet	Spring	0	0	0	0	0.52	0.37	0.11	0	30
Pond Inlet	Summer	0	0	0	0	0	0	1	0	82
Pond Inlet	Fall	0	0	0	0	0	0.24	0.76	0	58
BIC	Spring	0	0	0	0	0	0	0	1	11
BIC	Summer	0	0	0	0	0	0	0	1	9
BIC	Fall	0	0	0	0	0	0.26	0.2	0.54	143
BIS	Spring	0	0	0	0	0	0	0	1	3
BIS	Summer	0	0	0	0	0	0	0	1	1
BIS	Fall	0	0	0	0	0	0	0.04	0.96	18
BIS	Winter	0	0	0	0	0	0	0.09	0.91	0
Total removals		0	9	87	92	195	270	198	119	971



SS	JS	IB	MB	SI	AI	ES	EB	
1	0	0	0	0	0	0	0	Etah
0	0	1	0	0	0	0	0	Qaanaaq
0	1	0	0	0	0	0	0	GF Spring
0	1	0	0	0	0	0	0	GF Summer
0	1	0	0	0	0	0	0	GF Fall
0	0	0	1	0	0	0	0	Upernavik
0	0	0	0.01	0.97	0.02	0.01	0	Uummannaq
0	0	0	0.16	0	0.32	0.52	0	Disko Bay
0	0	0	0	0.88	0.1	0.03	0	CCA Spring
0	0	0	0	1	0	0	0	CCA Summer
0	0	0	0	0.87	0.11	0.01	0	CCA Fall
0	0	0	0	0.58	0.39	0.03	0	AB Spring
0	0	0	0	0	1	0	0	AB Summer
0	0	0	0	0	0.92	0.08	0	AB Fall
0	0	0	0	0.48	0.37	0.14	0	PI Spring
0	0	0	0	0	0	1	0	PI Summer
0	0	0	0	0.16	0.22	0.61	0	PI Fall
0	0	0	0	0.3	0.15	0.04	0.5	BIC Spring
0	0	0	0	0	0	0	1	BIC Summer
0	0	0	0	0.17	0.22	0.17	0.44	BIC Fall
0	0	0	0	0.3	0.15	0.04	0.5	BIS Spring
0	0	0	0	0	0	0	1	BIS Summer
0	0	0	0	0.24	0.03	0.05	0.68	BIS Fall
0	0	0	0	0.33	0.03	0.09	0.56	BIS Winter

Figure 3.—Allocation matrix A_{ij} with uncertainty in the designation "3. Partial Hunt" but no uncertainty in categories of "2. Probable zero" and "4. Probable hunt" (Z = 10,000). Mean proportions are presented in each cell. Abbreviations are defined in Figures 1 and 2.

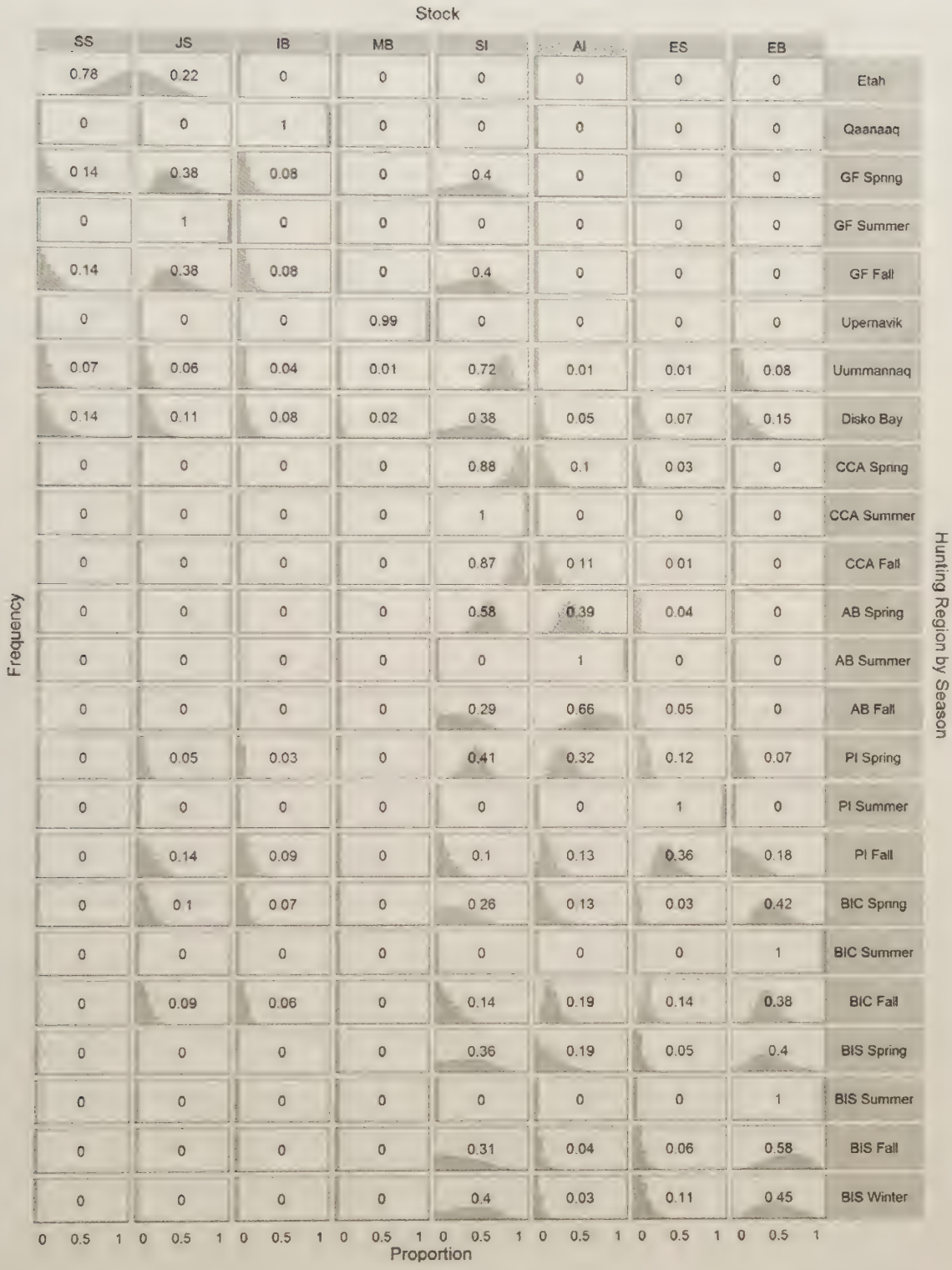


Figure 4.—Allocation matrix A_{ij} with uncertainty in the designation "3. Partial Hunt" and uncertainty in categories of "2. Probable zero" and "4. Probable hunt" (Z = 1). Mean proportions are presented in each cell. Abbreviations are defined in Figures 1 and 2.

Table 4.—Example of removals (and CV%) from each narwhal stock based on the allocation model output for Greenland and Canadian 2013 catches, under several assumptions. Z=10,000 includes uncertainty in the designation "3. Partial hunt" but assumes no uncertainty for "4. Probable zero", while Z=1 includes maximum uncertainty for "4. Probable zero". Fixed N assumes no uncertainty in abundance estimates while variable N includes uncertainty in abundance estimates.

Stocks	Smith Sound	Jones Sound	Inglefield Bredning	Melville Bay	Somerset Island	Admiralty Inlet	Eclipse Sound	East Baffin Island
Fixed Allocation Matrix	0	9	87	92	195	271	198	119
Z=10,000 fixed N	0 (46%)	9 (1%)	87 (0%)	93 (7%)	231 (8%)	273 (5%)	183 (8%)	94 (11%)
Z=1 fixed N	19 (46%)	40 (31%)	112 (8%)	84 (1%)	228 (9%)	241 (3%)	135 (5%)	112 (13%)
Z=10,000 variable N	0 (92%)	9 (1%)	87 (0%)	93 (9%)	233 (10%)	271 (12%)	185 (12%)	93 (20%)
Z=1 variable N	18 (70%)	40 (43%)	113 (10%)	84 (2%)	229 (13%)	240 (10%)	136 (10%)	111 (25%)

"5. Defined hunt", respectively. Lower values of Z ultimately result in different means and larger coefficients of variation in the allocation matrix (described below in the case study and in Fig. 3 and 4, and Table 4 where we explore Z values of 1 and 10,000).

Abundance

Abundance estimates with given mean (N) and coefficient of variation (CV) are assumed to follow a log-normal distribution with parameters μ and σ given by:

$$\mu = \log \frac{N^2}{\sqrt{N^2(1+CV^2)}}$$

and

$$\sigma = \sqrt{\log(1+CV^1)}$$

Monte-Carlo sampling is used to integrate uncertainty in abundance vectors N_{it} in the allocation matrix A_{ijt}. Draw 100,000 samples from a beta distribution for each cell in P_{ij} and 100,000 samples from a lognormal distribution for each value of N_{it} and calculate the value of A_{ijt} for each cell and each sample.

Stock Allocation Model

With the development of the allocation matrix, A_t, the full model is then:

$$S_t = T(A_t)\, H_t$$

Where,

S_t is a vector of the number of narwhal taken in hunts from each stock in year t,

$T(A_t)$ is the transposed A matrix in year t, and

H_t is a vector of the numbers of narwhal taken in hunts at each hunting area by season in year t.

As noted above, both A_t and H_t may be stochastic, thus S_t could also be stochastic.

Narwhal Case Study

To highlight the applicability of the model we use an example of narwhal hunted from eight different stocks: Smith Sound, Jones Sound, Inglefield Bredning, Melville Bay, Somerset Island, Admiralty Inlet, Eclipse Sound, and East Baffin Island (Fig. 1), in eleven different regions (Fig. 2) and in multiple seasons in some regions, for a total of 24 hunts.

Removals

For this case study we use landed catch data reported by the hunting communities in Canada and Greenland corrected for struck-but-lost animals in 2013 (Table 5; Watt and Hall[5]). The struck-but-lost factors (landed catches are multiplied by the struck-but-lost factors to estimate total removals) applied to the Arctic Bay, Pond Inlet, and Central Canadian Arctic hunts are 1.35, 1.15, and 1.09, respectively, and are based on loss rates reported by the communities of Arctic Bay, Pond Inlet, and Kugaaruk, Nunavut, Canada, for years between 2005 and 2010 (Watt and Hall[5]). An average struck-but-lost factor of 1.23 determined from these reported communities was used for hunts in Baffin Island Central, Grise Fiord, and Baffin Island South (Watt and Hall[5]). For hunts in Upernavik a factor of 1.15 is used, and for hunts in Etah, Qaanaaq, Ummannaq, and Disko Bay a factor of 1.30 was applied (Garde et al., 2019). The catch data is divided by season to reflect the seasonal availability quantified in the allocation matrix.

Table 5.—Removals of narwhal by season (landed catches including estimated struck-but-lost animals) for hunts in Canada and Greenland in 2013 (CCA: Central Canadian Arctic, BIC: Baffin Island Central, BIS: Baffin Island South; see Figure 2 for hunt locations).

Hunt	Season	Removals
Etah	Spring	0
Qaanaaq	Summer	87
Grise Fiord	Spring	5
Grise Fiord	Summer	0
Grise Fiord	Fall	4
Upernavik	Summer	82
Uommannaq	Fall	101
Disko Bay	Winter	66
CCA	Spring	1
CCA	Summer	33
CCA	Fall	23
Arctic Bay	Spring	43
Arctic Bay	Summer	167
Arctic Bay	Fall	4
Pond Inlet	Spring	30
Pond Inlet	Summer	82
Pond Inlet	Fall	58
BIC	Spring	11
BIC	Summer	9
BIC	Fall	143
BIS	Spring	3
BIS	Summer	1
BIS	Fall	18
BIS	Winter	0

Seasonal dates were defined based on narwhal movements in and out of the summering region for Canada and Greenland. For Greenland, spring was defined as 1 April–9 August, summer as 10 August–22 September, fall as 12 September–31 October, and winter as 1 November–31 March. For the Canadian catch data, spring was defined from 1 April–23 July, summer as 24 July–24 August, fall as 25 August–30 November, and winter as 1 December–31 March.

Abundance

The most recent abundance estimate for each stock from aerial surveys that

[5]Watt, C. A., and P. Hall. 2018. Catch statistics for narwhal (*Monodon monoceros*) in Canada from 1970-2015. Can. Tech. Rep. Fish. Aquat. Sci. 3270:vi + 209 p. (http://waves-vagues.dfo-mpo.gc.ca/).

have accounted for perception and availability bias is presented in Table 6 (Heide-Jørgensen et al., 2010; Doniol-Valcroze et al.[4]; Hansen et al.[6]).

Proportional Availability and Allocation Matrices

There are eight columns in the proportional availability and allocation matrices for narwhals that represent the individual summer stocks (Fig. 1). Twenty-four rows represent the hunting grounds (Fig. 2) divided by season where applicable; thus, for each stock and hunt there is a cell in the matrix. The value in each cell of the availability matrix was determined based on satellite telemetry data for narwhals collected over the last 25 years by both Canada and Greenland and expert opinion and local knowledge about the connection among stocks and hunting regions based on the designations 1–5 defined in Table 1.

A fixed version of the availability matrix defines "2. Probable zero" and "4. Probable hunt" as 0 and 1, respectively (Table 2). When applied to the abundance estimates, this yields a fixed version of the allocation matrix (Table 3). Catches are applied to the corresponding allocation proportions for each site, then summed for each stock to yield total removals. However, when uncertainty is considered, each cell contains a probability distribution, and a stochastic version of the proportional availability matrix for narwhals is produced (Table 7). The resulting distributions in the allocation matrix include uncertainty in both the proportional availabilities of narwhals and abundance estimates for the individual stocks (Fig. 3 for Z=10,000 and Fig. 4 for Z=1). The effect of adding uncertainty in abundance estimates on removals from each stock, for different values of Z, is shown in Table 4 and Figure 5. Since there are many cells designated as "2. Probable zero" for East Baffin Island, as uncertainty increases (lower values of Z) the takes from this stock go up since the probability that whales are taken from this stock in other hunting areas goes up (it is less likely that the true value is zero; Fig. 5 with distributions shown in Fig. 3 and 4).

Alternatively, for Admiralty Inlet there are no "2. Probable zero" or "4. Probable hunt" cells, but as Z decreases the uncertainty in the beta distribution for cells designated as "3. Partial hunt" goes up (or uncertainty in what the true proportion of the population available to hunters in other areas goes up). In this case, this results in the total take going down slightly (Fig. 5) since the true proportion for that stock goes down (Fig. 3 and 4). This reduction is particularly driven by the connection identified between Disko Bay and the Admiralty Inlet stock since only one of 42 tagged narwhals travelled into the Disko Bay hunting region. When uncertainty about whether this one whale represents a true proportion of the Admiralty Inlet stock available to hunters in Disko Bay goes up, the proportion of the catches allocated to that stock changes from 0.32 (Fig. 3) to only 0.05 (Fig. 4). The R code for running this model is provided in Supplementary Appendix A with the example narwhal data in Supplementary Appendix B.

Table 6.—The most recent abundance estimates with CVs and 95% confidence intervals (CI), estimated using the log-based method described by Buckland et al. (2001), for the eight narwhal stocks.

Stock	Year	Abundance estimate	CV	95% CI
Smith Sound	2013	16,360	0.65	5,110–52,373
Jones Sound	2013	12,694	0.33	6,760–23,838
Inglefield Bredning	2007	8,368	0.25	5,165–13,558
Melville Bay	2014	3,091	0.50	1,225–7,802
Somerset Island	2013	49,768	0.20	33,758–73,371
Admiralty Inlet	2013	35,043	0.42	15,904–77,214
Eclipse Sound	2013	10,489	0.24	6,596–16,679
East Baffin Island	2013	17,555	0.35	9,017–34,179

Table 7.—Stochastic availability matrix P_{ij} for narwhals from different summering stocks to different hunting regions (x/n; available (x) / total (n)) based on telemetry data (CCA: Central Canadian Arctic, BIC: Baffin Island Central, BIS: Baffin Island South; see Fig. 2 for hunt locations). 0 and 1 are fixed values, but ratios follow beta distributions ($\alpha = x+1$; $\beta = n-x+1$), all ratios for which $n=Z$ are sensitive to changes in Z. Other ratios reflect information from satellite telemetry data.

Hunt	Season	Smith Sound	Jones Sound	Inglefield Bredning	Melville Bay	Somerset Island	Admiralty Inlet	Eclipse Sound	East Baffin Island
Etah	Spring	1	0/Z	0	0	0	0	0	0
Qaanaaq	Summer	0	0	1	0	0	0	0	0
Grise Fiord	Spring	0/Z	1	0/Z	0	0/Z	0	0	0
Grise Fiord	Summer	0	1	0	0	0	0	0	0
Grise Fiord	Fall	0/Z	1	0/Z	0	0/Z	0	0	0
Upernavik	Summer	0	0	0	1	0	0	0	0
Uummannaq	Fall	0/Z	0/Z	0/Z	1/9	1	0/42	0/26	0/Z
Disko Bay	Winter	0/Z	0/Z	0/Z	1/7	0/Z	1/42	1/6	0/Z
CCA	Spring	0	0	0	0	1	0/4	0/5	0
CCA	Summer	0	0	0	0	1	0	0	0
CCA	Fall	0	0	0	0	1	7/42	1/26	0
Arctic Bay	Spring	0	0	0	0	1	1	1/5	0
Arctic Bay	Summer	0	0	0	0	0	1	0	0
Arctic Bay	Fall	0	0	0	0	0/Z	1	6/26	0
Pond Inlet	Spring	0	0/Z	0/Z	0	2/2	4/4	1	0/Z
Pond Inlet	Summer	0	0	0	0	0	0	1	0
Pond Inlet	Fall	0	0/Z	0/Z	0	0/14	4/42	1	0/Z
BIC	Spring	0	0/Z	0/Z	0	0/2	0/4	0/6	1
BIC	Summer	0	0	0	0	0	0	0	1
BIC	Fall	0	0/Z	0/Z	0	0/5	10/42	16/26	1
BIS	Spring	0	0	0	0	0/2	0/4	0/6	Z/Z
BIS	Summer	0	0	0	0	0	0	0	1
BIS	Fall	0	0	0	0	0/5	0/42	2/26	Z/Z
BIS	Winter	0	0	0	0	0/2	0/42	1/6	Z/Z

Discussion

The model can allocate hunted animals to specific stocks for each hunting season and site by incorporating information on animal movements and migration, which is essential for

[6]Hansen, R. G., S. Fossette, N. H. Nielsen, M. H. S. Sinding, D. Borchers, and M. P. Heide-Jørgensen. 2015. Abundance of narwhals in Melville Bay in 2012 and 2014. NAMMCO/SC/22-JCNB/SWG/2015-JWG/14. R. Hansen, Greenland Institute of Natural Resources c/o Greenland Representation, Strandgade 91, 2. sal, 1401 København K, Denmark.

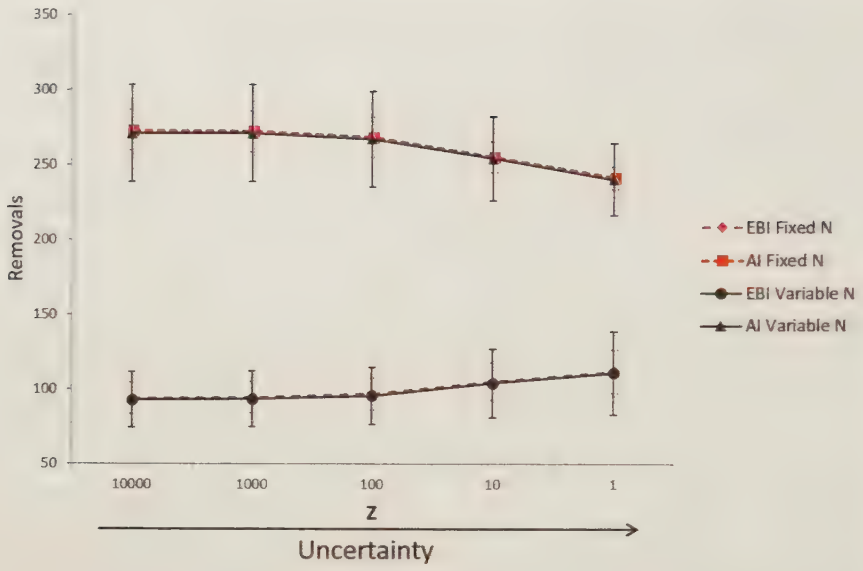


Figure 5.—An example of the effect of the uncertainty parameter Z and uncertainty in abundance estimates on removals (± SD) from the Admiralty Inlet (AI) and East Baffin Island (EBI) stocks, based on allocation of Greenland and Canadian catches from 2013. Fixed N assumes no uncertainty in abundance estimates while Variable N includes uncertainty in abundance estimates. Uncertainty increases as Z decreases in cells with a designation of "2. Probable zero".

sustainable stock management (Ogburn et al., 2017). The model output can be improved with increased information on animal movements, which may mean increased satellite tagging efforts, or quantification of other movement indices (chemical tracers, sampling and analysis of DNA from hunted whales, local knowledge, etc.). With limited information on some of the stocks in the narwhal case study, the model output relies on local knowledge and expert opinion, and the sensitivity analysis shows how changes in these parameters impact the catch allocations and suggests incorporation of uncertainty is critical for stocks for which little movement information is available. The model can easily be adapted for use for other hunted or fished species and provides a pathway for incorporating movement information into conservation and management (Allen and Singh, 2016; Ogburn et al., 2017). For use on other species, sensitivity analysis of the chosen Z value is important and model users will need to decide the level of certainty they are comfortable with since changes to the Z value impact removals for individual stocks.

For the narwhal case study, the success of the model for managing stocks relies on international collaboration between Canada and Greenland. By combining information about narwhal movements through sharing of telemetry data, abundance estimates, expert opinion, and local knowledge from both countries we are able to have a more meaningful and comprehensive view of the situation. If the model is to be adapted for other hunted animals, we strongly suggest that incorporation of data from all geographic areas where the animal migrates is needed to ensure the model is capturing all data and uncertainty that exists across the species range. Harrison et al. (2018) evaluated movement data from 14 species of marine predators in relation to geopolitical boundaries and found that all of the species evaluated entered numerous jurisdictions, highlighting the need for international management. Conservation of many of the species evaluated will require collaboration among many countries and regions within a country (Harrison et al., 2018). Our modeling framework provides one method for evaluating stock overlap and is a successful example of international co-management.

In the narwhal case study, even with collaboration between nations and sharing of data, there is uncertainty in the data and subsequent model output. Telemetry data does not exist for all the narwhal stocks, and for those that have movement information, there is not uniform coverage of different geographical areas or seasons. Although all stocks have an abundance estimate, trends in abundance are unavailable for some stocks or are based on relatively few data points and it is uncertain how this could affect the model results (e.g., future loss of sea ice could result in changes in seasonal narwhal movements that may result in changes to abundance estimates for specific stocks and this may not be captured accurately without frequent abundance estimates).

Catch statistics may not be precise; in particular the struck-but-lost rate which is applied may not be accurate for all hunt types in different seasons, which may result in an over or under estimate of the total catches. Struck-but-lost rates specific to different hunting regions would be beneficial and would allow incorporation of uncertainty in this parameter for the different stocks. Finally, although the model can allocate catches to the different stocks, it is unknown how management decisions (e.g., to which season to allocate most catches) may influence stock sustainability in the long run.

Despite the limitations of the model used here, this framework provides a direct link between movement information and management policy. Gathering animal telemetry data is costly and ecologically interesting but is often not used to directly impact conservation and policy decisions (McGowan et al., 2017). The framework presented here can be used to identify data gaps, and allow for prioritization of research specific to stocks for which there exists high uncertainty about movement.

Through evaluation of the management implications and how decisions may change with more or less certainty about movements, researchers and managers can evaluate the pros (improved management) and cons (financial investment) of acquiring more telemetry data (McGowan et al., 2017). Management of hunted animals often only considers part of the life cycle or life history of the animal and ignores movement into other management jurisdictions (Ogburn et al., 2017). This model bridges that gap and can allow for a more complete understanding of the life history of the animal, ultimately leading to more sustainable management. Few examples of hunt management based on movement data exist in the literature, but a banding study on mallard ducks by Nichols et al. (1995) evaluated patterns of geographic variation in harvest rates, essentially using movement as a method to measure harvest reporting and gain information on harvest statistics. Similarly, by using reported harvest and movement data together to allocate catches, the model presented here can directly inform management decisions. The model presented here is only as good as the data that goes into it and an understanding of animal movement across all seasons and throughout its geographical range is needed for it to be successful. This model can only allocate catches to specific stocks after they have occurred, and thus, hunt allocation or setting of future quotas for the different hunts is the next step (see Witting et al., 2019).

Acknowledgments

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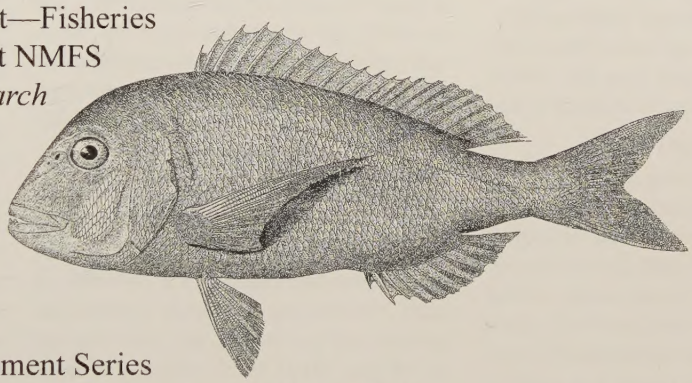

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The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to the *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700 (available from the SPO website).

Manuscripts must be double-spaced throughout, and a complete manuscript normally includes a title page, a short abstract, text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

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Keep titles, headings, subheadings, and the abstract short and clear. Because abstracts are circulated by abstracting agencies, it is important that they represent the research clearly and concisely. Headings within each section must be short, reflect a logical sequence, and follow the rules of multiple subdivision (i.e., there can be no subdivision without at least two items).

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The entire text should be intelligible to interdisciplinary readers; therefore, all acronyms, abbreviations, and technical terms should be spelled out the first time they are mentioned. The scientific names of species must be written out the first time they are mentioned; subsequent mention of scientific names may be abbreviated. Follow the U.S. Government Printing Office Style Manual (2008 ed.) and the Scientific Style and Format: the CSE Manual for Authors, Editors, and Publishers (2014, 8th ed.) published by the Council of Science Editors.for editorial style, and the most current issue of the American Fisheries Society's Common and Scientific Names of Fishes from the United States and Canada for fish nomenclature. Only journal titles, scientific names (genera and species), and vessel names should be italicized. Dates should be written as follows: 11 November 2013. Measurements should be expressed in metric units, e.g., metric tons as (t); other equivalent units may also be listed in parenthesis. Common abbreviations and symbols such as mm, m, g. ml, mg, and °C (without periods) may be used with numerals. The numeral one (1) should be typed as a one, not as a lower-case el (l). Write out the numbers zero through nine unless they form part of measurement units (e.g., nine fish but 9 mm).

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